APPLICATION OF THE EDYS MODEL TO EVALUATE CONTROL METHODS FOR INVASIVE PLANTS AT FORT CARSON, COLORADO

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14. ABSTRACT
SERDP project CS1145 explored alternative control and assessment strategies for knapweeds and annual brome, two non-indigenous plant taxa, on US military installations. These plant taxa infest large areas of the Western United States and they are a major concern for military bases. Heavy maneuvering of troops and equipment causes large disturbances where native vegetation is stressed, soil is lost, and invasive noxious plants often take hold. Replacing stands of noxious weeds with native plant communities on military training grounds will reduce soil erosion and create more sustainable ecological systems. Non-indigenous invasive plants can also reduce and destroy forage for livestock and wildlife, displace native plant species, increase fire frequency, reduce recreational opportunities, and can poison domestic animals. It is imperative to find economical, ecologically sound methods to control these weeds to minimize control costs and degradation of military training grounds.

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1.0 SUMMARY

This section presents the results of the simulation modeling portion of the overall project designed to evaluate several methods of control of Japanese brome and spotted knapweed at Fort Carson, Colorado. The field experiment portion of the project tested several control methods on these invasive species over study period of four years. The purposes of simulation modeling were to 1) evaluate the long-term effects of the control methods by projecting the results of the field experiments over a 50-year period and 2) provide a tool by which the interactions among various control methods can be evaluated and the effects of variations in environmental factors such as precipitation, grazing, and military training, might have on the experimental results. Simulation modeling is the only effective method of evaluating experimental results over longer periods of time and of efficiently evaluating expected responses to relatively large numbers of variations in environmental factors.

The simulation modeling for this project was conducted using the EDYS ecological model. EDYS is a PC-based, mechanistic model that provides a powerful tool for evaluating ecological responses to a wide variety of natural and anthropogenic stressors over time, on spatial scales ranging from small plots to large landscapes and watersheds. EDYS has been applied to over 40 ecological communities within deserts, forests, grasslands, shrublands, wetlands, and highly disturbed areas. The objective of the EDYS application was to evaluate long-term ecological responses to a set of management options experimentally tested in Fort Carson to control two invasive species and rates and patterns of vegetation recovery through secondary succession.

The first step was to validate the EDYS model for this site. This was done by parameterizing the model for the initial conditions at the beginning of the field experiments, simulating the changes in the vegetation over the four-year experimental period, and then comparing these simulation results to data from the field experiments. Following this validation procedure, 50-year simulation runs were conducted to evaluate long-term responses to the control methods. Effects of variations in environmental and management factors were then simulated to estimate how these factors might impact the control of Japanese brome and spotted knapweed and the recovery of the native vegetation.

The field experiments were applied to two sites at Fort Carson and EDYS was applied to these same two sites. One site was dominated by Japanese brome and the other was dominated by spotted knapweed. The first site was designed the brome site, and the second site was designed the knapweed site. Each site consisted of a 4000 m^2 treatment area, divided by into 40 10 m x 10 m treatment plots. The EDYS footprint consisted of 40 cells at each of the sites, each cell corresponding to a treatment plot. Thirty plant species were included in this application, along with the four treatments (prescribed fire/biological control, seeding to native and introduced perennial species, application of sugar, and microbial application). The four treatments were modeled as single factors and each of the combinations used in the experimental study. A control (no treatment applied) was also included for each site. In addition to treatments, natural ecological stressors (precipitation fluctuations, natural fire, intra- and inter-specific competition, ecological succession, natural herbivory by insects and rabbits), livestock grazing, and military training (tracked and wheeled vehicles) were also included as environmental factors.

At the brome site, Japanese brome was the dominant species at the beginning of the study, but

four years later the production of this species had drastically declined. The drought conditions of 2002 and 2003 were probably the main reason for this effect. The EDYS model did not simulate well this decline in Japanese brome, probably because the precipitation data that was used for modeling did not represent accurately the precipitation that was received at the study site. The decline in Japanese brome dominance by 2003 was followed by an increase in bindweed dominance. This replacement in species dominance was not observed in the EDYS simulations because Japanese brome was not as affected in the simulations as it was in the field.

At the knapweed site, the population of spotted knapweed dominated the plant community at the beginning of the study. However, as occurred in the brome site with Japanese brome, spotted knapweed declined drastically four years later. The main reason for the decline in spotted knapweed production was the below average precipitation that occurred in 2002 and 2003. This decline and the replacement of western wheatgrass as the dominant species was well simulated by the EDYS model. At the knapweed site, the EDYS simulations of biomass production did not generally differ statistically from the field sampling estimations.

In the brome site long-term simulations, Japanese brome and bindweed had negligible biomass by Year 50, while western wheatgrass became the dominant species. At the knapweed site, the population of spotted knapweed was lost by Year 10 and western wheatgrass, twistspine prickly pear, and soapweed became the dominant species. The treatments applied to the study plots had little effect in the long-term simulations. This may have been the result of the short-term application of the treatments. Fire was applied only the first year, microbial inoculation was applied two years, and sugar was applied only for four years. The long-term simulated replacement of weedy invasive species by native and introduced perennials, corresponds well to results obtained in long-term studies found in the literature. The EDYS model simulated well these vegetation changes through time, showing to be a valuable tool to forecast plant community dynamics under different management scenarios.

Spotted knapweed and Japanese brome declined in their respective communities and showed great susceptibility to drought conditions. Spotted knapweed was eliminated from the community within 10 years, while Japanese brome survived at low production levels until Year 50. The faster elimination of spotted knapweed may indicate higher susceptibility to drought than Japanese brome. The effect of biological control agents was not clearly demonstrated, perhaps because it was masked by the overriding influence of the drought.

When grazing was included in the model, no substantial impacts on vegetation total aboveground biomass were seen. Species composition was different at the end of the 50-year simulation. Twistspine pricklypear disappeared from the plots whereas in ungrazed plots it was a major species. Western wheatgrass biomass increased with all levels of grazing and, at the end of 50 years, it was the dominant species. Most other grasses and forbs were gone by the end of the simulation.

When impacts of an M-1 Abrams tank passing through the plots in Year 5 were included in the model, there was no long-term change seen in vegetation biomass and species composition. When impacts of an M-1 Abrams tank or a HMMWV passing through the plots every five years were included in the model, total aboveground biomass was much lower at Year 50 than in non-impacted plots. Species composition was also negatively affected. Biomass of twistspine pricklypear, soapweed, and western wheatgrass, the major species in undisturbed plots, decreased substantially.

No species increased and most other grasses and forbs had disappeared by the end of the simulation.

These modeling results suggest that the plant community in Fort Carson would tend to become a grassland dominated by western wheatgrass over the long-term, provided that the precipitation regimes are similar to the ones registered over the past 50 years and that no further disturbance occurred. Disturbances such as military vehicle training will change biomass production but do not appear to change the major species composition in a 50-year simulation.

2.0 INTRODUCTION

The establishment of non-native invasive species on disturbed lands that were previously dominated by native plants, and the long-term dominance of these sites by these invasive species, are the results of interactions among a number of ecological and management factors. Likewise, the successful control of these invasive species and re-establishment of the native plant communities also involves complex ecological interactions over time. The challenge of successful re-establishment is further complicated by variations in management and climatic scenarios that a site might be exposed to over the period of re-establishment.

Field experiments are important for the purposes of testing concepts and refining methodologies relative to control of invasive species and the re-establishment of native plant communities. Without field experimentation, revegetation would be based entirely on trial and error. However, the usefulness of field experimentation is limited, in part, by 1) relatively short time periods they are conducted over and 2) the environmental conditions that occurred during the experimental period. The cost of field experiments increase the longer the experiments are conducted and the more environmental variations that are included in the design.

Simulation modeling provides one method of addressing the limitations of field experiments. When combined with field experiments, simulation modeling can be used to evaluate the results of the field experiments over longer periods of time and under many more variations of environmental factors than are practical with field experiments. Successful simulation modeling is a two-step process. First, the simulation model being used must be shown to be able to adequately simulate the results of the field experiments. Otherwise, there is little reason to have confidence in the results of the model relative to longer-term responses and variations in environmental factors. Once this validation process is accomplished, the second step of applying the model to longer-term responses and variations in environmental factors can be implemented.

The simulation model used in this project is the EDYS (Ecological DYnamics Simulation) model. EDYS is a PC-based, mechanistic, spatially explicit, and temporally dynamic simulation model (Childress and McLendon 1999, Childress et al. 1999a, 1999b). It simulates changes in soil, water, plant, animal, and landscape components resulting from natural and anthropogenic ecological stressors (McLendon et al. 1999a, Childress et al. 2001). EDYS has been applied to a wide variety of ecosystems, management scenarios, and disturbance regimes in Arizona, California, Colorado, Maine, Montana, Nevada, New Mexico, Texas, Utah, Washington, Wyoming, Australia, and Indonesia (McLendon et al. 1996, 1999a, 1999b, 1999c, 2000a, 2001, 2002), Ash and Walker (1999), and Chiles and McLendon (2004).

At Fort Carson, EDYS was applied first to the 4-year experimental study to determine its potential for simulating the observed experimental responses in the plant communities. EDYS was then used to evaluate the relative impacts of 8 natural ecological stressors and 16 management options on the vegetation dynamics of the two experimental sites over a 50-year period. This report presents details of the EDYS application at Fort Carson, including parameterization values, source references, and simulation results.

3.0 GENERAL DESCRIPTION OF EDYS

This section presents a broad over-view of the EDYS model. More detailed presentations are available in Childress and McLendon (1999) and Childress et al. (1999a, 1999b, 2002).

3.1 EDYS Modules

EDYS consists of Climate, Soil, Hydrologic, Plant, Animal, Stressor, Spatial, Landscape, and Management modules. Climatic inputs can be historical or stochastically generated, or a combination of both. The Soil Module is divided into layers (horizons, subhorizons, or artificial layers), the number, depth, and physical and chemical characteristics of which are site-specific for each application. The Hydrologic Module provides for infiltration and water movement through the soil profile, surface movement of water, surface erosion, sediment movement, subsurface movement of water, and changes in water quality (Figure 1).

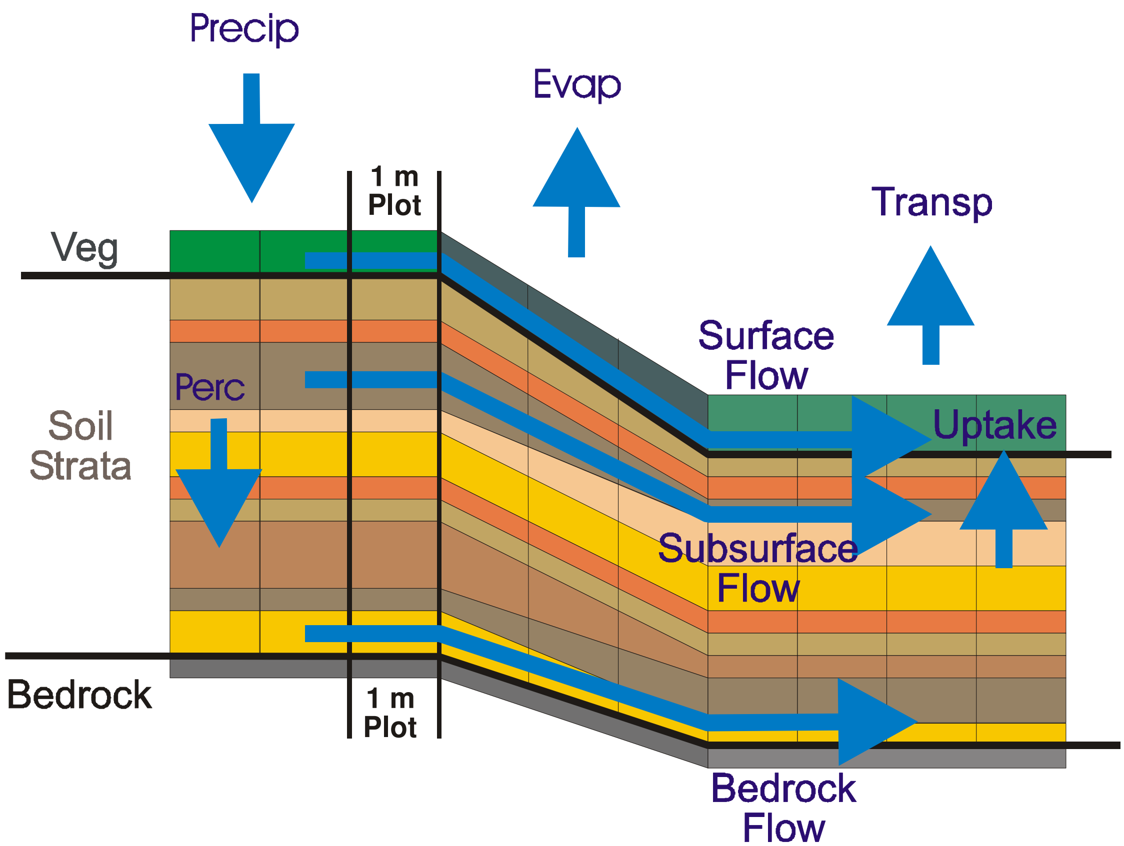

Figure 1. Hydrological Dynamics in the EDYS Landscape Module

The Plant Module includes above- and belowground components for each species included in each user-defined suite (Figure 2).

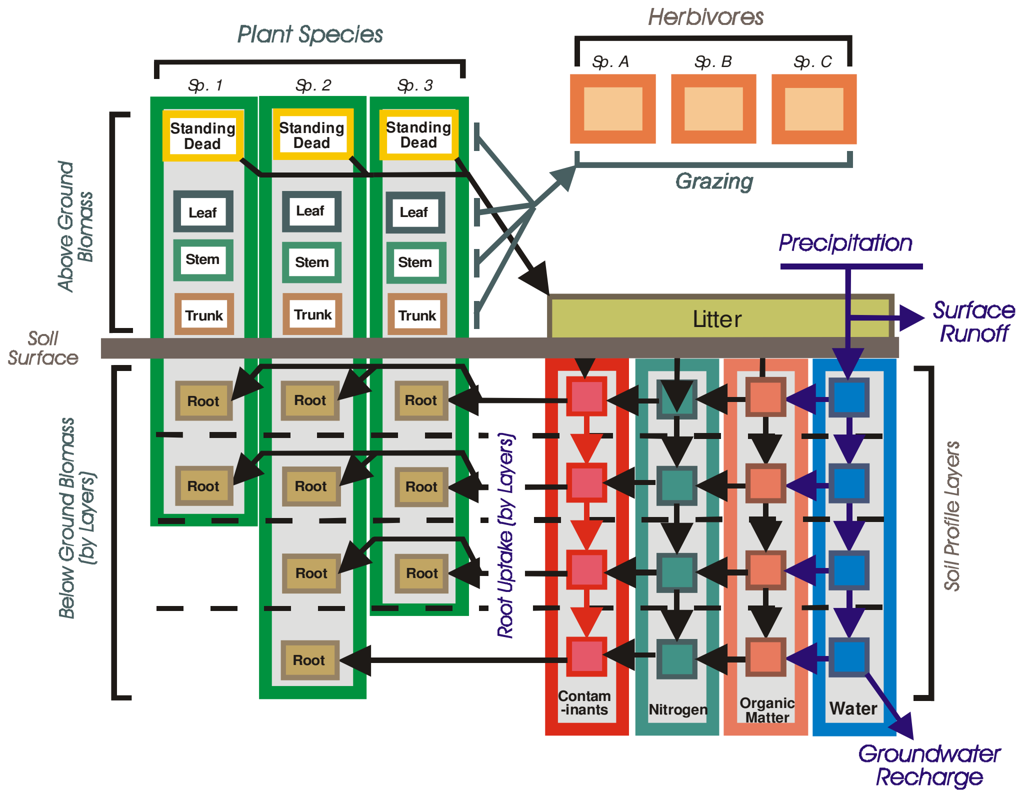

Figure 2. EDYS Plot-Level Structure

Plant growth is dynamic in relation to plant components (roots, trunk, stems, leaves, seeds, and standing dead), season, resource requirements (water, nutrients, sunlight), and stressors (e.g., herbivory, competition, fire, trampling, chemical contaminants). The Animal Module consists of basic population parameters and diet attributes (preferences, utilization potential, competitive success) for each species (e.g., insects, rodent, native ungulates, livestock). The Stressor Module includes drought, nutrient availability, fire, herbivory, trampling (foot and vehicle), contaminants, shading, and competition (soil moisture, nutrients, food). The Spatial Module allows growth of individual plants (e.g., trees) and distribution patterns (e.g., colonies, fire patterns, soil heterogeneity) to be explicitly represented in the simulations. The Landscape Module (Figure 3) allows for multi-scale simulations: fine scale (1 m^2 or smaller), patches (e.g., 100 m^2), communities (e.g., 1-10 hectares), and landscapes and watersheds (1 km^2 and larger). Time intervals vary from day (e.g., precipitation events, plant water demand, fire, herbivory), to month (e.g., species composition), to year and longer (e.g., climatic cycles).

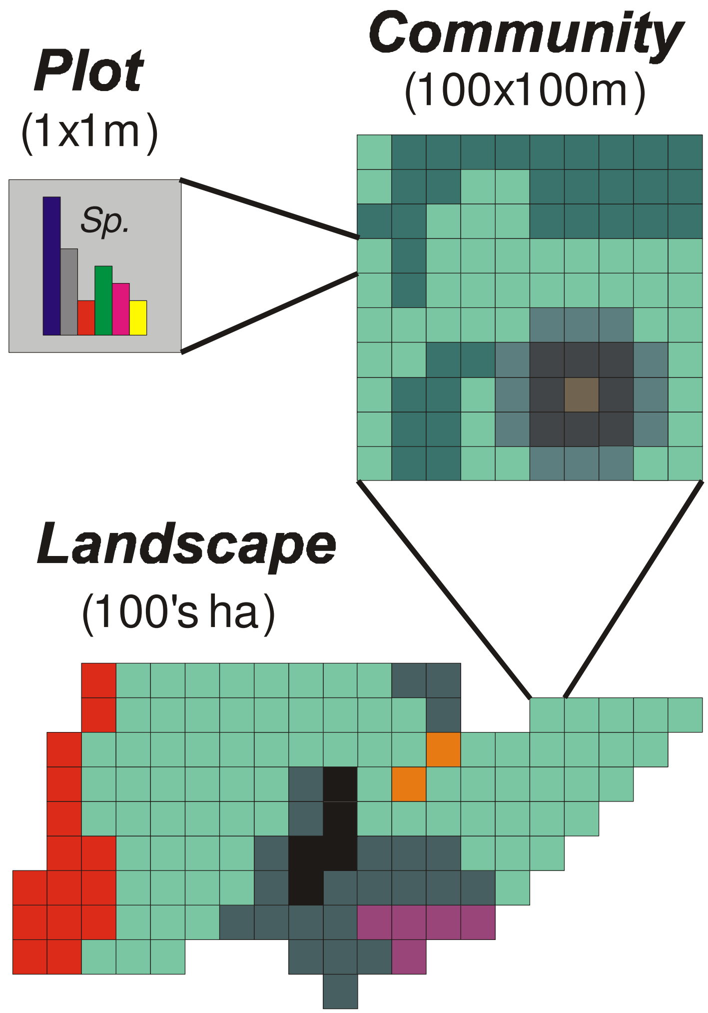

Figure 3. Scaling of the Plot, Community, and Landscape Modules in EDYS

3.2 EDYS Simulation Outputs

Each simulation run of EDYS produces a large volume of data for all state variables (e.g., plant biomasses, soil water and nutrient contents, total surface runoff) and processes (e.g., water and nutrient transport and balances, plant production). These data are stored in a series of large text tables, typically on a monthly basis. Many of these data are also presented in graphical displays at the end of the simulation run (e.g., Figure 4).

These extensive output files serve a number of useful functions. These data are required for accurately testing and calibrating the EDYS application for particular communities and sites. In addition, these data can be sent in "real time" to other models running simultaneously.

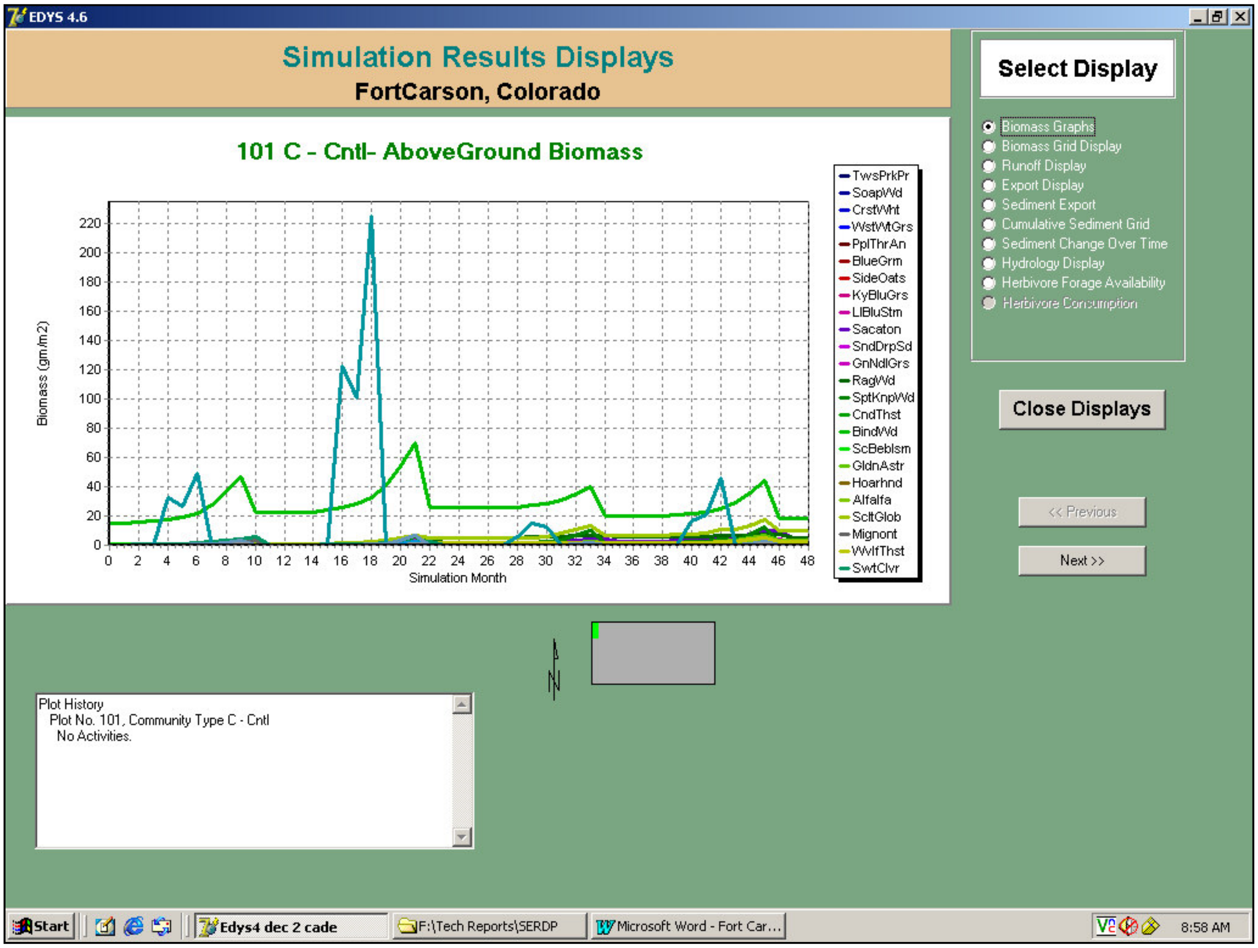

Figure 4. Monthly Aboveground Biomasses of Plant Species in a 4-yr Simulation Run of the Brome Community at Fort Carson

Among the various outputs produced in each EDYS simulation run are tables describing water pools and dynamics as well as summary graphical displays of total landscape runoff, export, and landscape hydrology (Figure 5). These outputs allow projection of the effects of different climatic regimes, ecological stressors, vegetation dynamics, and management practices on surface and subsurface water quantity and quality.

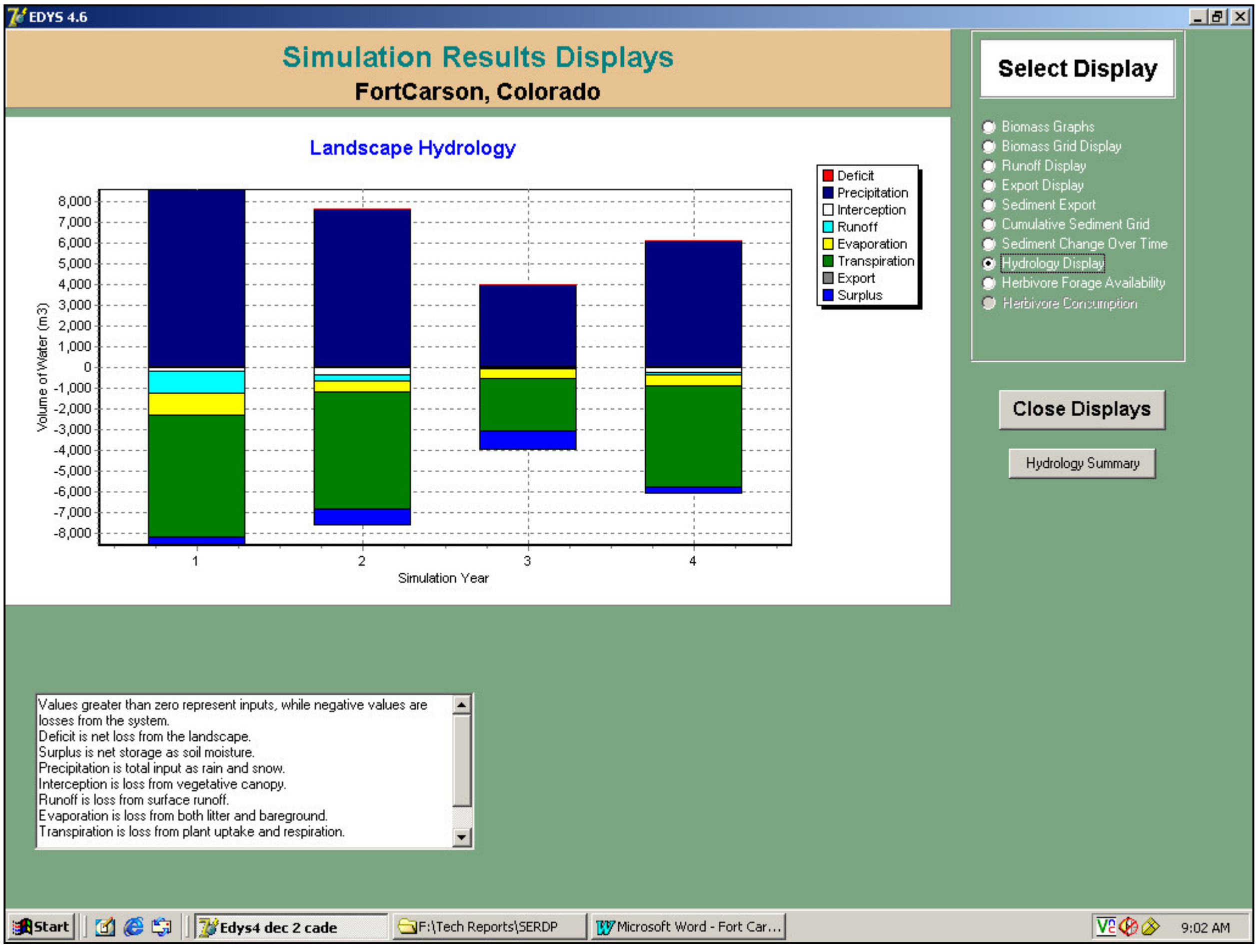

Figure 5. Landscape Hydrology at the Brome Community at Fort Carson

4.0 FORT CARSON LANDSCAPE

Fort Carson is a 1295 km^2 military base located in El Paso County in southeastern Colorado. The landscape selected for this EDYS application consisted of two study sites, each 4000 m^2 in size. The two sites contain vegetation characteristic of a shortgrass plains foothill shrubland transition community. The first site was dominated by Japanese brome (*Bromus japonicus* Thunb. ex Murr.) and was located within the Turkey Creek Recreation Area. The second site was invaded by spotted knapweed (*Centaurea maculosa*) and was located along Little Turkey Creek adjacent to the Turkey Creek Recreation Area.

4.1 Climatic Data

A 55-year daily precipitation file for the landscape was created using existing precipitation data from Colorado Springs Airport (Latitude 38°83'N, Longitude 104°82'W). The 55-year mean annual precipitation value is 43.06 cm (16.95 inches). Annual totals are presented in Table 1 and average monthly values are presented in Table 2.

Table 1. Annual precipitation totals (cm) used in the Fort Carson Landscape EDYS application

Year	Total (cm)	Year	Total (cm)	Year	Total (cm)	Year	Total (cm)
1949	32.03	1963	36.14	1977	49.30	1991	46.10
1950	30.91	1964	23.19	1978	35.33	1992	38.86
1951	41.68	1965	66.19	1979	49.94	1993	50.90
1952	29.21	1966	34.39	1980	51.31	1994	68.22
1953	28.02	1967	50.57	1981	44.75	1995	60.60
1954	40.79	1968	32.89	1982	57.33	1996	49.45
1955	35.53	1969	54.91	1983	39.17	1997	59.87
1956	27.28	1970	43.48	1984	54.71	1998	43.18
1957	66.93	1971	31.72	1985	47.35	1999	71.65
1958	48.46	1972	52.25	1986	42.90	2000	44.27
1959	45.82	1973	37.44	1987	47.90	2001	39.70
1960	30.00	1974	25.73	1988	33.40	2002	21.54
1961	40.77	1975	31.50	1989	40.82	2003	31.30
1962	27.31	1976	53.04	1990	50.04		

Table 2. Monthly precipitation totals (cm) for the Fort Carson Landscape, averaged over a 55-year period.

Month	Average (cm)	Standard Deviation
Jan	0.87	1.09
Feb	1.43	0.98
Mar	2.53	1.76
Apr	3.73	3.42
May	5.64	3.59
Jun	5.84	3.78
Jul	7.34	3.44
Aug	7.27	4.15
Sep	3.43	2.48
Oct	2.20	2.34
Nov	1.73	1.73
Dec	1.05	1.31

4.2 Spatial Data

A 10 m x 10 m cell size was used in this application. For each study site, 40 cells were included in the landscape mosaic. A uniform elevation throughout the landscape was assumed because impacts of the treatments were being analyzed on a small scale.

4.3 Edaphic Data

One soil series (Neville fine sandy loam) was used in the EDYS application based on NRCS soils maps for the area. Physical data for this series was taken from the NRCS Soil Survey for El Paso County. Organic matter and soil nitrogen (total and available) data were compiled from soil profiles listed in Soil Survey Staff (1975). Specifics for this soil series are presented in Appendix 1.

In EDYS, initial values are entered for each of the soil variables for the Neville soil series. These are the values that appear in Appendix 1. Values for each of these variables can change during a simulation run, depending on the dynamics of environmental conditions. For example, organic matter content in a given layer will decrease daily because of decomposition, but may also increase daily because of organic matter input from root death or from litter inputs. Nitrogen content will vary on a daily basis because of 1) plant uptake, 2) release from decomposition and mineralization, 3) downward transport through infiltration of soil water, and 4) inputs from atmospheric deposition. Depth of the surface layer may decrease because of erosion. Bulk density may increase because of soil compaction from vehicle training.

4.4 Vegetation Data

4.4.1 Plant Species

The number of plant species included in an EDYS simulation is flexible and is specified in the initial parameterization. Regardless of how many species are selected, the suite remains a simplified representation of the actual vegetation, since some species are excluded. In order to account for overall community dynamics (e.g., total aboveground biomass), the ecological contribution of species not specifically included in the model must somehow be considered. This is accomplished in EDYS by using composite species.

In EDYS, a composite species consists of a major species plus those minor species most ecologically similar to the respective species. For example, *Convolvulus equitans* is a relatively minor species at the Fort Carson brome site, averaging less than 1 g/m^2 in 2000. Ecologically, this species is similar to *Convolvulus arvensis*, which is a major species at the brome site. In EDYS, the biomass values for *Convolvulus equitans* are added to the values for *Convolvulus arvensis*. The minor species *Clematis ligusticifolia* and *Evolvulus nuttallianus* are added to the biomass of *Convolvulus arvensis* as well. This allows for the simulated biomass totals at a site to be comparable to the sampled totals and allows for proper mass balance accounting for such components as litter, water use, and nitrogen dynamics. In effect, this estimates the responses of the minor species on the basis of the responses of their most similar major species.

Species occurring in minor amounts, that are not otherwise of primary ecological or management importance, are included in a composite species for three reasons. First, there generally are very little ecological data available on minor species, therefore parameterization values used in the model for these minor species would simply be estimated from the data for the major species. Second, the more that estimated values are used, the more "noise" is entered into the simulation results. Third, adding more species increases the run times and the memory required for each simulation. These increases are acceptable if they result from a more accurate representation of the simulated system. However, these increases are not acceptable if the increase in complexity is the result of more, but inaccurate, data.

Field data collected in the study plots provided information on plant species to be used in this application. A total of 183 species have been reported on the experimental plots, however, most of these 183 species occur in very low amounts. By eliminating the minor species, 30 plant species were chosen for the Fort Carson application (Table 4). Biomass values for the minor species were included in the total aboveground biomass for the respective composite species (Table 5). Of the 109 species recorded at the brome site in 2000, six accounted for 85% of the relative biomass (Table 6). Of the 152 species recorded at the knapweed site in 2000, nine accounted for 78% of the relative biomass (Table 6).

Table 4. Thirty plant species selected for inclusion in the Fort Carson Landscape EDYS application.

Species	Common Name	Mean Biomass (g/m^2) 2000-2001	Lifeform
Opuntia macrorhiza	Twistspine pricklypear	2.51	Shrub/Succulent
Yucca glauca	Soapweed	1.98	Shrub/Succulent
Agropyron cristatum	Crested wheatgrass	0.10	Perennial grass
Pascopyrum smithii	Western wheatgrass	17.57	Perennial grass
Aristida purpurea	Purple threeawn	1.79	Perennial grass
Bouteloua curtipendula	Sideoats grama	0.44	Perennial grass
Bouteloua gracilis	Blue grama	3.29	Perennial grass
Poa pratensis	Kentucky bluegrass	1.15	Perennial grass
Schizachyrium scoparium	Little bluestem	1.64	Perennial grass
Sporobolus airoides	Sacaton	0.36	Perennial grass
Sporobolus cryptandrus	Sand dropseed	0.30	Perennial grass
Nassella viridula	Green needlegrass	4.88	Perennial grass
Ambrosia psilostachya	Ragweed	0.83	Perennial forb
Centaurea maculosa	Spotted knapweed	21.19	Perennial forb
Cirsium arvense	Canada thistle	2.33	Perennial forb
Convolvulus arvensis	Bindweed	19.93	Perennial forb
Gaura coccinea	Scarlet beeblossum	0.71	Perennial forb
Heterotheca villosa	Golden aster	1.47	Perennial forb
Marrubium vulgare	Hoarhound	0.83	Perennial forb
Medicago sativa	Alfalfa	0.00	Perennial forb
Reseda lutea	Mignonette	7.04	Perennial forb
Sphaeralcea coccinea	Orange globemallow	0.30	Perennial forb
Cirsium undulatum	Wavyleaf thistle	0.90	Biennial forb
Melilotus officinalis	Sweetclover	4.70	Biennial forb
Bromus japonicus	Japanese brome	16.95	Annual grass
Chenopodium album	Lambsquarters	0.18	Annual forb
Helianthus petiolaris	Sunflower	0.26	Annual forb
Lesquerella montana	Bladderpod	0.08	Annual forb
Salsola kali	Russian thistle	0.01	Annual forb
Sisymbrium altissimum	Tansymustard	0.22	Annual forb

Table 5. List of the 30 composite species, along with the species included in each composite, used in the EDYS application for Fort Carson landscape.

Composite Species	Included Species
Opuntia macrorhiza	*Opuntia macrorhiza, Opuntia polyacantha*
Yucca glauca	*Yucca glauca, Cercocarpus montanus, Juniperus monosperma, Prunus americana, Purshia tridentata, Quercus gambelli, Rhus aromatica* ssp. *trilobata, Ribes cereum, Rosa woodsii, Sabina monosperma, Pinus edulis*
Agropyron cristatum	*Agropyron cristatum, Dactylis glomerata*
Pascopyrum smithii	*Pascopyrum smithii, Agrostis stolonifera, Bromopsis inermis, Elymus canadensis, Thinopyrum intermedium*
Aristida purpurea	*Aristida purpurea, Aristida divaricata, Schedonnardus paniculatus*
Bouteloua curtipendula	*Bouteloua curtipendula, Muhlenbergia racemosa*
Bouteloua gracilis	*Bouteloua gracilis, Chondrosum hirsutum, Chondrosum prostratum, Muhlenbergia montana, Muhlenbergia sp.*
Poa pratensis	*Poa pratensis, Carex filifolia, Carex aurea, Carex* sp., *Poa* sp., *Poa compressa, Poa secunda*
Schizachyrium scoparium	*Schizachyrium scoparium, Andropogon gerardii*
Sporobolus airoides	*Sporobolus airoides*
Sporobolus cryptandrus	*Sporobolus cryptandrus, Eragrostis intermedia*
Nassella viridula	*Nassella viridula, Achnatherum hymenoides, Achnatherum robustum, Elymus elymoides, Koeleria macrantha, Stipa comata*
Ambrosia psilostachya	*Ambrosia psilostachya, Ambrosia acanthicarpa, Ambrosia trifida, Artemisia frigida, Artemisia campestris, Artemisia ludoviciana, Artemisia ludoviciana* var. *ludoviciana, Glandularia bipinnatifida, Erigeron engelmannii, Erigeron pumilus, Erigeron* sp., *Liatris punctata, Ratibida columnifera, Senecio* sp., *Taraxacum officinale*
Centaurea maculosa	*Centaurea maculosa, Brickellia eupatorioides, Conyza canadensis, Lygodesmia juncea, Melampodium leucanthum, Stephanomeria pauciflora, Symphyotrichum ericoides, Talinum parviflorum, Thelesperma megapotamicum, Tetraneuris acaulis*
Cirsium arvense	*Cirsium arvense, Carduus nutans* L. ssp. *macrolepsis*
Convolvulus arvensis	*Convolvulus arvensis, Clematis ligusticifolia, Convolvulus equitans, Evolvulus nuttallianus*
Gaura coccinea	*Gaura coccinea, Gaura mollis, Ipomopsis* sp., *Oenothera coronopifolia, Polyctenium fremontii*
Heterotheca villosa	*Heterotheca villosa, Eriogonum umbellatum* var. *umbellatum, Gutierrezia sarothrae, Machaeranthera pinnatifida, Machaeranthera* sp., *Salvia dorrii, Salvia reflexa, Chrysothamnus nauseosus*
Marrubium vulgare	*Marrubium vulgare, Argyrochosma fendleri, Argemone hispida, Argemone polyanthemus, Mentzelia nuda, Mentzelia sp., Nepeta cataria, Penstemon virgatus, Penstemon angustifolius* var. *venosus, Penstemon hallii, Penstemon palmeri, Penstemon secundiflorus*
Medicago sativa	*Medicago sativa, Dalea candida, Dalea purpurea, Lupinus arbustus, Psoralidium tenuiflorum*
Reseda lutea	*Reseda lutea, Adenolinum lewisii, Allium textile, Asclepias pumila, Asclepias subverticillata, Calochortus gunnisonii, Hybanthus verticillatus, Mirabilis linearis, Polygonum aviculare, Polygonum douglasii, Polygonum persicaria, Polygonum ramosissimum, Pterogonum alatum*
Sphaeralcea coccinea	*Sphaeralcea coccinea, Cerastium beerengianum, Hypericum perforatum, Lithospermum incisum, Physalis hispida, Physalis virginiana, Physalis subulata var. neomexicana, Quincula lobata, Tradescantia occidentalis, Viola nuttallii*
Cirsium undulatum	*Cirsium undulatum, Cirsium vulgare, Verbascum thapsus, Tragopogon dubius*
Melilotus officinalis	*Melilotus officinalis, Astragalus drummondii, Vicia americana*
Bromus japonicus	*Bromus japonicus, Bromus tectorum, Echinochloa crus-galli, Echinochloa muricata* var. *microstachya, Eragrostis cilianensis, Monroa squarrosa, Panicum capillare*

Table 5. (continued)

Chenopodium album	*Chenopodium album, Amaranthus retroflexus, Chenopodium watsonii, Chenopodium atrovirens, Chenopodium desiccatum, Chamaesyce glyptosperma, Chenopodium leptophyllum, Euphorbia dentata* var. *dentata, Phlox gracilis* ssp. *humilis, Plantago patagonica, Portulaca olaracea, Solanum triflorum, Tribulus terrestris*
Helianthus petiolaris	*Helianthus petiolaris, Dyssodia papposa, Erodium cicutarium, Grindelia squarrosa, Helianthus annuus, Thelesperma filifolium, Verbena bracteata*
Lesquerella montana	*Lesquerella montana, Camelina microcarpa, Lappula occidentalis* var. *occidentalis, Lappula redowski, Silene antirrhina, Vaccaria hispanica*
Salsola kali	*Salsola kali, Hedeoma hispida, Kochia scoparia, Salsola australis*
Sisymbrium altissimum	*Sisymbrium altissimum, Lepidium densiflorum, Descurainia pinnata, Descurainia sophia, Lactuca serriola, Lactuca tatarica* var. *pulchella*

Table 6. Relative biomass values (% mean composition) for individual species at the Fort Carson Training Center in 2000 and 2001.

	Brome Site		Knapweed Site	
Species	**2000[a]**	**2001[a]**	**2000[a]**	**2001[a]**
Opuntia macrorhiza	0.30	0.21	4.90	3.56
Yucca glauca			4.91	2.59
Agropyron cristatum		0.26		
Pascopyrum smithii	18.92	19.25	3.70	7.72
Aristida purpurea	t	t	3.99	2.64
Bouteoua curtipendula	t	t	1.36	0.32
Bouteloua gracilis	0.38	t	3.99	6.62
Poa pratensis	0.07	t	1.31	2.53
Schizachyrium scoparium			3.33	2.72
Sporobolus airoides	t	t	t	1.13
Sporobolus cryptandrus	t	t	0.27	1.67
Nassella viridula	5.65	10.48		1.97
Ambrosia psilostachya	0.78	1.52	0.19	0.63
Centaurea maculosa	t		34.65	41.37
Cirsium arvense	3.09	4.90	t	
Convolvulus arvensis	26.36	32.25	t	t
Gaura coccinea	0.84	0.58	0.13	0.15
Heterotheca villosa	t	t	2.13	2.99
Marrubium vulgare	1.10	0.14		
Medicago sativa	t	t		
Reseda lutea	9.32	7.67		
Sphaeralcea coccinea	0.23	0.20	0.25	0.21
Cirsium undulatum	1.13	t	0.17	t
Melilotus officinalis	0.12	t	16.30	2.25
Bromus japonicus	21.35	16.77	1.03	1.87
Chenopodium album	0.17	0.28		0.16
Helianthus petiolaris	0.33	0.61	t	t
Lesquerella montana	t	t	t	0.15
Salsola kali	t	t	t	t
Sisymbrium altissimum	0.24	0.39	t	0.11
Total biomass (g/m^2)	75.53	38.44	23.97	31.03

[a]Numbers may not add up to 100 because some minor species were left off the list, but they still contributed to total percent composition.

4.4.2 Parameterization Data

Parameterization data were supplied to EDYS in 27 parameterization matrices (Appendix 2). The values contained in these matrices were derived from several sources: 1) site-specific data collected from the Fort Carson experimental plots, 2) data from the scientific literature, 3) data from the MWH database, and 4) authors expert opinions.

4.5 Animal Data

Two native animal species were simulated in this application: insects and rabbits. Herbivory by insects and rabbits was assumed to be uniform throughout the study sites and was based on animal densities. Densities used for insects were 3, 6, and 12 individuals per square meter. Rabbits were simulated at densities of 0.30, 0.56, and 0.78 individuals per hectare.

4.6 Natural Stressors

Five natural stressors were included in this application: interspecific competition for belowground resources (water, nutrients), drought, nitrogen availability, fire, and herbivory by native animals (insects, rabbits). In EDYS, ecological responses by each plant species to each of these stressors are modelled by use of 1) supply and demand and 2) ecophysiological relationships defined by the parameterization matrices (Appendix 2). For example, successional patterns are simulated by changes in relative biomass of the species over time in response to the interaction of these stressors. This might function in the following manner. If species A has a higher water use efficiency than species B, species A will produce a higher proportion of biomass than species B in dry years, provided an equal amount of water is available to both species. However, species B may have a different root architecture than species A, which allows species B to access the water in deeper soil layers unavailable to species A. Therefore, species B may be more "protected" from drought than species A because of its deeper root system. In addition, fires may be more frequent in dry years and species B may be better adapted to fire stress than species A. Both of these factors, deeper roots and better adaptation to fire, may provide species B with sufficient competitive advantage over species A to offset the higher water-use efficiency of species A.

Daily precipitation values are used based on the constructed historic data set (Table 1). These constitute the default precipitation level for the application. The values can be increased or decreased by the user to simulate above-average precipitation or drought. Nutrient content, primarily nitrogen content, is set by the soil content of the soil series and each soil layer may vary. The default frequency for natural fire is monthly. Its occurrence and spread are based on appropriate fuel load, moisture content, and stochastic factor.

4.7 Management Scenarios

Management scenarios include optional values for those factors directly influenced by human activities. Seven management options are included in this application: 1) knapweed seedhead weevil and root-boring moth (knapweed site only), 2) seeding of native and introduced perennial grasses, 3) prescribed fire (brome site only), 4) sugar application, 5) microbial inoculation, 6) livestock grazing, and 7) military training (tracked vehicles, wheeled vehicles).

4.8 Model Implementation of Treatments

Knapweed root weevil (*Cyphocleonus achates*) and root moth (*Agapeta zoegana*) treatment was modelled by simulating the impact of both insects on plant roots in the EDYS model. To apply this treatment, the start month and year are selected to simulate introduction of the insects. Frequency of infestation must also be designated. Because these insects will spread over time, a monthly rate of spread (meters) has to be entered as well. To simulate impacts of these insects on knapweed, an impact proportion (i.e., amount of reduction in root biomass) is set. The actual impact of root feeders was determined by analyzing results of field experiments at the Fort Carson site. An extensive literature search was also conducted to determine how these insects impact diffuse knapweed growth and spread.

The seeding option places a given amount of native and introduced perennial species seed into the seedbank of each cell within the selected area. The seeding treatment is simulated by designating the seed mix, seed amount, and the areas, dates, and frequency of seeding. Some of the species in the seed mix applied at Fort Carson were not included in the EDYS application and, therefore, substitutions were made. Table 7 lists the species included in the seed mix and those species included in the EDYS seeding scenario, along with amount of seed applied.

Table 7. Species included in the seeding mix applied to the Fort Carson Landscape EDYS application.

Species in Seeding Mix	lbs/acre
Perennial grasses:	
Pascopyrum smithii	5.98
Bouteloua curtipendula	2.99
Agropyron cristatum	2.02
Sporobolus airoides	0.20
Sporobolus cryptandrus	0.21
Perennial forb:	
Medicago sativa	1.00

For the prescribed fire treatment, the user selects when the burn is to take place (month, year) and how often the prescribed fire will occur (e.g., every four years). The effectiveness and the spatial distribution of the fire are simulated based on the composition, biomass, and distribution of the vegetation in each cell within the burn area at the time of the fire. Fire was prescribed on the brome site in October, 2000. The knapweed site did not receive a prescribed fire.

The purpose of the sugar treatment was to reduce nitrogen availability in the soils of the study plots by applying a carbon source (i.e., sugar) to immobilize soil nitrogen. To simulate the impact, the user selects the year and frequency of application and how much the free nitrogen in the soil is reduced. The soil free nitrogen is allowed to recover one month after application. The impact of sugar application was determined by analyzing results from Fort Carson study plots.

For the microbial inoculation treatment, the user selects the year and month of donor soil application and the frequency with which soil is applied. A water/nutrient uptake factor (i.e., how much amount of nutrient and water uptake is enhanced) and a decomposition rate factor (i.e., how much rate of decomposition is enhanced) are chosen that allow EDYS to effectively simulate impacts of microbial inoculation. The impact of microbial inoculation on plant water and nutrient uptake and decomposition dynamics was estimated by analyzing plant biomass data collected in study plots.

Four stocking rates are included in the application that the user may select for a particular simulation. The four standard stocking rates are no grazing, light grazing (64 acres/AU), moderate grazing (32 acres/AU), and heavy grazing (21 acres/AU). The user may also designate any alternative stocking rate, rather than only select from the four standard stocking rates. Year-long grazing is assumed for this application.

Military training is implemented by selecting 1) which of four vehicle types (M-1 Abrams, M-2 Bradley, HMMWV, truck) and number of each type to be included, 2) the training area in which the activities will occur, 3) the intensity of the training (i.e., how many vehicle miles per vehicle type), and 4) when the training occurs (months, years). Additional vehicle types, can be added to future updates of the model if desired. Once these parameters are designated, EDYS calculates ecological impact in one of two methods, depending on which is designated by the user. In both methods, there is an impact associated with each vehicle type on each plant species for each pass of the vehicle (Matrix 24, Appendix 2). In the first method, this calculated impact is distributed stochastically across the designated training area, and in the second method it is averaged over the entire designated training area.

5.0 RESULTS OF FIELD EXPERIMENTS

5.1 Field Data

The goal of the field experiment was to determine how experimental treatments would impact spread of the invasive species *Bromus japonicus* (Japanese brome) and *Centaurea maculosa* (spotted knapweed). The impact of four factors on vegetation dynamics of the two training areas (brome and knapweed sites) was studied at Fort Carson. At the brome site these four factors included 1) two levels of fire (fire, no fire), 2) two levels of seeding (seeded, not seeded), 3) two levels of nitrogen limitation (sugar added, no sugar added), and 4) two levels of microbial inoculation (inoculated, not inoculated). At the knapweed sites these four factors included 1) two levels of knapweed root-feeding insects (bug, no bug), 2) two levels of seeding (seeded, not seeded), 3) two levels of nitrogen limitation (sugar added, no sugar added), and 4) two levels of microbial inoculation (inoculated, not inoculated).

For each site (brome or knapweed) there were eight different combinations of the four treatments, including:

1. No fire/no bug, no seed, no sugar, no inoculation
2. Fire/bug, no seed, no sugar, no inoculation
3. Fire/bug, seed, no sugar, no inoculation
4. Fire/bug, no seed, sugar, no inoculation
5. Fire/bug, seed, sugar, no inoculation
6. Fire/bug, seed, no sugar, inoculation
7. Fire/bug, no seed, sugar, inoculation
8. Fire/bug, seed, sugar, inoculation.

There were five replications of each treatment combination, for a total of 40 plots per site. Table 8 lists the date, frequency, and amount of each treatment applied to the Fort Carson study sites.

Table 8. Timing of treatment application in the brome and knapweed sites at Fort Carson.

Site	Treatment	Date Applied	Frequency	Amount Applied
Knapweed	Biological control (*Agapeta zoegana* and *Cycphocleonus achates*)	July 18-19, 2000	1 time only	700 adult insects (20 per plot on 35 plots)
Brome	Prescribed fire	October 20, 2000	1 time only	35 of 40 plots burned
Knapweed and Brome	Seeding	Nov. 3, 2000 April 2, 2002	Twice in four years	240 g seed/plot (on 35 plots)
Knapweed and Brome	Sugar application	May, July, Sept, Nov, 2000 and April, May, June, Nov, 2001-2003	4 times per year	1600 kg carbon/ha/yr (on 35 plots)
Knapweed and Brome	Microbial inoculation	Nov. 3, 2000 and Spring, 2002	Twice in four years	400 g dry soil per plot (on 35 plots)

Aboveground clippable biomass was collected each year in June at all of the experimental plots and data for the brome and knapweed sites are listed in Tables 9 and 10 respectively. These tables give the average biomass of the major species from five replicate plots for each treatment combination. Total biomass is the sum of all species present in the plot (major species plus minor species not listed). The major species at the Fort Carson brome site were Japanese brome and bindweed (*Convolvulus arvensis*) and the major species at the knapweed site were spotted knapweed and western wheatgrass (*Pascopyrum smithii*).

Substantial changes in the vegetation occurred between 2000 and 2004 at both the brome and knapweed sites. In the control plots at the brome site, Japanese brome increased in the second year and then decreased greatly in the third and fourth years (Table 9). In most of the plots that were subjected to a prescribed burn, Japanese brome decreased in the second and third years and then began increasing again in the fourth year. In the third year of the field study (2002), annual precipitation was about 50% of the 55-year average annual precipitation. This low rainfall may have prevented vegetation from recovering from the burn in the second year and, in control plots, decreased vegetation growth.

Table 9. Total aboveground clippable biomass for major species (composite species) at the brome site at Fort Carson. Numbers shown are averages of five plots. BRJA is *Bromus japonicus*, COAR4 is *Convolvulus arvensis*, NAVI4 is *Nassella viridula*, PASM is *Pascopyrum smithii*, RELU is *Reseda lutea*. Total is the sum of the biomass of all species present on the plots.

Trt	Year	Fire	Seed	Sugar	Soil	BRJA	COAR4	NAVI4	PASM	RELU	Total
1	2000	no burn	no seed	no sugar	uninoc	85.76	33.10	0.00	0.69	2.15	135.57
1	2001	no burn	no seed	no sugar	uninoc	113.96	36.20	0.09	0.00	1.71	166.27
1	2002	no burn	no seed	no sugar	uninoc	0.10	6.22	0.00	0.00	2.13	10.60
1	2003	no burn	no seed	no sugar	uninoc	1.80	137.36	0.00	0.00	2.34	152.85
2	2000	burn	no seed	no sugar	uninoc	24.82	19.84	24.09	16.26	23.42	137.94
2	2001	burn	no seed	no sugar	uninoc	29.91	39.05	21.69	36.78	23.23	179.74
2	2002	burn	no seed	no sugar	uninoc	0.00	3.43	4.04	1.17	5.62	14.91
2	2003	burn	no seed	no sugar	uninoc	8.01	96.55	7.45	39.00	56.01	235.33
3	2000	burn	seed	no sugar	uninoc	37.77	14.70	30.66	9.91	41.24	158.36
3	2001	burn	seed	no sugar	uninoc	9.67	49.24	36.73	16.24	34.79	163.90
3	2002	burn	seed	no sugar	uninoc	0.02	1.08	3.44	0.73	5.20	11.62
3	2003	burn	seed	no sugar	uninoc	3.20	81.20	10.28	9.71	37.54	182.55
4	2000	burn	no seed	sugar	uninoc	37.53	38.74	31.08	14.45	27.52	164.17
4	2001	burn	no seed	sugar	uninoc	8.69	59.78	14.82	10.62	12.57	125.75
4	2002	burn	no seed	sugar	uninoc	0.00	6.26	5.39	0.45	5.12	18.35
4	2003	burn	no seed	sugar	uninoc	7.67	96.12	8.97	16.43	19.55	162.20
5	2000	burn	seed	sugar	uninoc	30.52	51.22	26.80	46.83	6.58	174.22
5	2001	burn	seed	sugar	uninoc	3.05	73.78	18.23	39.74	2.29	143.16
5	2002	burn	seed	sugar	uninoc	0.00	8.29	2.22	4.24	0.51	16.70
5	2003	burn	seed	sugar	uninoc	6.24	92.70	4.99	70.40	3.02	185.79
6	2000	burn	seed	no sugar	inoc	23.47	18.40	15.19	59.79	19.39	140.60
6	2001	burn	seed	no sugar	inoc	13.45	32.32	15.47	74.03	10.71	163.29
6	2002	burn	seed	no sugar	inoc	0.00	2.63	1.55	1.40	6.98	12.96
6	2003	burn	seed	no sugar	inoc	18.41	47.68	3.14	90.69	16.16	194.10
7	2000	burn	no seed	sugar	inoc	31.57	35.94	9.64	40.16	10.85	142.11
7	2001	burn	no seed	sugar	inoc	10.96	63.11	14.30	41.79	8.66	150.16
7	2002	burn	no seed	sugar	inoc	0.01	6.06	2.23	1.68	0.32	10.77
7	2003	burn	no seed	sugar	inoc	6.97	75.56	3.97	58.92	13.81	167.60
8	2000	burn	seed	sugar	inoc	38.23	29.14	16.83	34.76	0.27	133.85
8	2001	burn	seed	sugar	inoc	16.60	45.72	9.08	23.98	1.89	137.89
8	2002	burn	seed	sugar	inoc	0.13	2.69	1.63	3.50	0.37	8.95
8	2003	burn	seed	sugar	inoc	3.15	63.89	5.17	55.28	7.00	162.94

At the knapweed site, spotted knapweed increased in all treatment plots in the second year and decreased dramatically in the third year. In the fourth year knapweed biomass began to increase again in most plots (Table 10). Two biological control insects, *Agapeta zoegana*, and *Cyphocleonus achates*, were released on the experimental plots and eventually were found in control plots as well. Callaway et al. (1999) found that *Agapeta* had no significant direct effect on the biomass of knapweed during a two-year field experiment with spotted knapweed. Other studies have found that the damage of *Agapeta zoegana* to spotted knapweed is sublethal, but it can reduce plant density (Muller-Scharer 1991, Story et al. 2000, Smith and Story 2003). *Cyphocleonus achates* has been reported to be one of the most damaging biological control agents spotted knapweed (Story et al. 1996, Jacobs et al. 2000). Effects include reduction in seed and flower production and overall growth and density (Steinger and Muller Scharer 1992, Jacobs et al. 2000, Clark et al. 2001). Thus, although the root weevil has the potential to reduce spotted knapweed growth and plant density, no declines in knapweed growth were measured except in the third year of the study. This coincides with the year of the drought and, therefore, it is difficult to determine impacts due to the insects. In the fourth year, knapweed increased again in most plots and so any impacts from the insects were temporary.

Total biomass increased in most plots in the second year and then dramatically declined in the third year, probably due to the drought. Field data show that biomass of all plots (both knapweed and brome sites) was very low in the third year, most likely due to drought.

Table 10. Total aboveground clippable biomass for major species (composite species) at the knapweed site at Fort Carson. Numbers shown are averages for five plots. ACMA9 is *Centaurea maculosa*, CHGR15 is *Bouteloua gracilis*, HEAN3 is *Helianthus annuus*, MEOF is *Melilotus officinalis*, PASM is *Pascopyrum smithii*, SPCR is *Sporobolus cryptandrus*, YUGL is *Yucca glauca*. Total is the sum of the biomass of all species present on the plots.

Trt	Year	Bug	Seed	Sugar	Soil	ACMA9	CHGR15	MEOF	PASM	SPCR	YUGL	Total
1	2000	nobug	NoSeed	nosugar	uninoc	56.31	0.86	4.61	7.86	0.31	15.72	102.51
1	2001	nobug	NoSeed	nosugar	uninoc	86.35	2.26	0.25	21.07	2.85	5.25	164.04
1	2002	nobug	NoSeed	nosugar	uninoc	0.16	2.19	0.00	1.42	1.68	0.19	7.99
1	2003	nobug	NoSeed	nosugar	uninoc	12.52	11.83	1.76	86.23	42.22	8.09	275.70
2	2000	bug	NoSeed	nosugar	uninoc	29.46	2.17	19.58	0.31	0.36	6.80	126.04
2	2001	bug	NoSeed	nosugar	uninoc	48.35	14.36	0.49	1.13	2.02	2.26	124.30
2	2002	bug	NoSeed	nosugar	uninoc	0.01	3.31	0.00	0.19	0.91	5.39	13.99
2	2003	bug	NoSeed	nosugar	uninoc	3.27	25.43	0.38	18.94	8.67	9.70	148.81
3	2000	bug	Seed	nosugar	uninoc	29.16	4.35	19.39	1.15	0.03	3.33	108.52
3	2001	bug	Seed	nosugar	uninoc	64.35	12.66	10.45	8.75	3.66	3.69	152.59
3	2002	bug	Seed	nosugar	uninoc	0.16	3.43	0.00	0.72	2.51	2.39	13.16
3	2003	bug	Seed	nosugar	uninoc	0.27	23.31	0.74	16.84	25.67	6.63	170.18
4	2000	bug	NoSeed	sugar	uninoc	52.27	2.05	16.58	1.28	0.15	6.53	95.15
4	2001	bug	NoSeed	sugar	uninoc	63.53	4.86	0.84	6.21	1.00	1.47	106.72
4	2002	bug	NoSeed	sugar	uninoc	0.94	1.68	0.00	0.71	0.65	1.79	9.54
4	2003	bug	NoSeed	sugar	uninoc	6.80	12.05	1.32	14.45	14.40	1.04	131.31
5	2000	bug	Seed	sugar	uninoc	25.52	7.51	12.83	2.87	0.08	3.52	80.14
5	2001	bug	Seed	sugar	uninoc	27.04	8.16	2.91	7.11	1.73	3.55	95.20
5	2002	bug	Seed	sugar	uninoc	0.09	2.68	0.00	0.48	0.73	1.13	7.68
5	2003	bug	Seed	sugar	uninoc	2.48	16.91	2.04	34.56	12.04	1.81	102.15
6	2000	bug	Seed	nosugar	inoc	21.00	3.46	15.94	5.55	0.08	19.29	87.06
6	2001	bug	Seed	nosugar	inoc	48.18	7.14	0.37	12.38	1.04	12.68	119.32
6	2002	bug	Seed	nosugar	inoc	0.66	2.36	0.00	0.55	0.82	18.51	26.52
6	2003	bug	Seed	nosugar	inoc	9.01	14.76	0.70	17.49	20.01	3.09	145.19
7	2000	bug	NoSeed	sugar	inoc	23.82	7.56	21.04	6.97	0.66	0.32	92.56
7	2001	bug	NoSeed	sugar	inoc	39.11	6.79	1.70	15.40	0.98	0.33	109.27
7	2002	bug	NoSeed	sugar	inoc	0.64	2.35	0.00	1.18	0.17	0.03	8.66
7	2003	bug	NoSeed	sugar	inoc	3.17	17.42	3.80	32.99	2.39	0.60	134.73
8	2000	bug	Seed	sugar	inoc	38.17	2.65	15.99	4.01	0.41	0.00	75.11
8	2001	bug	Seed	sugar	inoc	50.51	9.46	5.94	5.19	3.32	3.05	121.48
8	2002	bug	Seed	sugar	inoc	0.00	2.12	0.00	1.07	1.06	0.07	6.77
8	2003	bug	Seed	sugar	inoc	1.13	29.96	1.99	40.83	3.55	1.37	174.91

Because not all possible combinations of treatments were applied to field plots, to determine effects of a particular treatment the results from two different treatment combinations must be compared. For example, to determine the effects of sugar application, the results of Treatment 2 (burn, no seed, no sugar, no inoculation) and Treatment 4 (burn, no seed, sugar, no inoculation) may be compared.

The results of treatment comparisons for the brome site are shown in Tables 11 (burning), 12 (seeding), 13 (sugar application), and 14 (soil inoculation). Burning was effective in reducing Japanese brome in the year following the prescribed fire (74% reduction), but at the end of four years the burned plots had higher average brome biomass than the plots that were not burned. Total biomass was 29% lower in the year following the burn, but at the end of four years plots had, on average, 23% more biomass.

Table 11. Effect of prescribed burning on total aboveground biomass (g/m2) at the brome site at Fort Carson.

Species	Year	No burn	Burn
Total above-ground biomass	2000	133	96
	2001	160	114
	2002	10	10
	2003	150	185
Japanese brome	2000	86	25
	2001	114	30
	2002	0	0
	2003	2	8
Bindweed	2000	33	20
	2001	36	39
	2002	6	3
	2003	137	97
Perennial grasses	2000	1	40
	2001	0	60
	2002	0	5
	2003	0	46
Perennial forbs	2000	12	40
	2001	10	47
	2002	3	6
	2003	8	67
Biennial forbs	2000	1	10
	2001	1	1
	2002	0	0
	2003	0	3
Annual forbs	2000	1	3
	2001	3	3
	2002	0	0
	2003	3	15

Seeding of native and introduced perennial species caused aboveground biomass of Japanese brome to be 45% lower in seeded plots than in unseeded plots after four years (Table 12). Total aboveground biomass was lower in seeded than in unseeded plots. Biomass of perennial forbs was also lower (23%), but no change was seen in bindweed. Perennial grasses and annual forbs showed a mixed response, increasing in some plots and decreasing in others.

Table 12. Effect of seeding on vegetation total aboveground biomass (g/m^2) at the brome site at Fort Carson.

Species	Year	Burn	Burn/ seed	Burn/ sugar	Burn/ sugar/ seed	Burn/ sugar/ soil	Burn/ sugar/soil/ seed
Total above-ground biomass	2000	96	108	118	97	92	81
	2001	114	105	99	83	94	99
	2002	10	7	12	10	7	4
	2003	185	159	136	109	104	100
Japanese brome	2000	25	38	38	31	32	38
	2001	30	10	9	3	11	17
	2002	0	0	0	0	0	0
	2003	8	3	8	6	7	3
Bindweed	2000	20	15	39	51	36	29
	2001	39	49	60	74	63	46
	2002	3	1	6	8	6	3
	2003	97	81	96	93	76	64
Perennial grasses	2000	40	50	46	74	50	53
	2001	60	55	26	58	56	33
	2002	5	5	6	6	4	5
	2003	46	22	26	75	63	61
Perennial forbs	2000	40	51	37	15	25	5
	2001	47	45	29	7	19	38
	2002	6	6	6	1	1	1
	2003	67	43	28	9	19	21
Biennial forbs	2000	10	4	5	0	0	9
	2001	1	1	1	1	0	1
	2002	0	0	0	0	0	0
	2003	3	0	1	0	0	0
Annual forbs	2000	3	0	0	0	0	0
	2001	3	4	1	0	0	3
	2002	0	0	0	0	0	0
	2003	15	33	4	3	3	15

After four years of sugar application, there was no consistent change (i.e., some plots had higher biomass and some plots had lower biomass) in brome and perennial grass biomass (Table 13). No change was seen in total aboveground biomass. The biomass of bindweed was, on average, 113% higher in plots receiving sugar application than in those not receiving sugar application. The biomass of annual forbs was 41% lower and perennial forbs was 40% lower in plots receiving sugar application than in those not having sugar applied. Sugar application increases growth of heterotrophic microorganisms and causes a drop in available nitrogen. This condition should favor slower-growing perennial species, but these results were not observed.

Table 13. Effect of sugar application on vegetation total aboveground biomass (g/m^2) at the brome site at Fort Carson.

Species	Year	Burn	Burn/ sugar	Burn/ seed	Burn/ seed/ sugar	Burn/ seed/ soil	Burn/ seed/soil/ sugar
Total above-ground biomass	2000	96	118	108	97	66	81
	2001	114	99	105	83	69	99
	2002	10	12	7	10	10	4
	2003	185	136	159	109	98	100
Japanese brome	2000	25	38	38	31	23	38
	2001	30	9	10	3	13	17
	2002	0	0	0	0	0	0
	2003	8	8	3	6	18	3
Bindweed	2000	20	39	15	51	18	29
	2001	39	60	49	74	32	46
	2002	3	6	1	8	3	3
	2003	97	96	81	93	48	64
Perennial grasses	2000	40	46	50	74	75	53
	2001	60	26	55	58	90	33
	2002	5	6	5	6	3	5
	2003	46	26	22	75	94	61
Perennial forbs	2000	40	37	51	15	24	5
	2001	47	29	45	7	19	38
	2002	6	6	6	1	7	1
	2003	67	28	43	9	20	21
Biennial forbs	2000	10	5	4	0	0	9
	2001	1	1	1	1	1	1
	2002	0	0	0	0	0	0
	2003	3	1	0	0	0	0
Annual forbs	2000	3	0	0	0	0	0
	2001	3	1	4	0	8	3
	2002	0	0	0	0	0	0
	2003	15	4	33	3	14	15

After four years of soil inoculation, there was no consistent change in brome, although average brome biomass was higher in inoculated plots than in uninoculated plots (Table 14). Annual and perennial forb biomass did not show a consistent change. The biomass of bindweed was 31% lower in plots being inoculation with soil than in those not being inoculated. The biomass of perennial grasses was 44% higher in plots that were inoculated than in those that were not inoculated.

Table 14. Effect of soil inoculation on vegetation total aboveground biomass (g/m^2) at the brome site at Fort Carson.

Species	Year	Burn/ seed	Burn/ seed/ soil	Burn/ sugar	Burn/ sugar/ soil	Burn/ seed/ sugar	Burn/ seed/ sugar/soil
Total above-ground biomass	2000	108	66	118	92	97	81
	2001	105	69	99	94	83	99
	2002	7	10	12	7	10	4
	2003	159	98	136	104	109	100
Japanese brome	2000	38	23	38	32	31	38
	2001	10	13	9	11	3	17
	2002	0	0	0	0	0	0
	2003	3	18	8	7	6	3
Bindweed	2000	15	18	39	36	51	29
	2001	49	32	60	63	74	46
	2002	1	3	6	6	8	3
	2003	81	48	96	76	93	64
Perennial grasses	2000	50	75	46	50	74	53
	2001	55	90	26	56	58	33
	2002	5	3	6	4	6	5
	2003	22	94	26	63	75	61
Perennial forbs	2000	51	24	37	25	15	5
	2001	45	19	29	19	7	38
	2002	6	7	6	1	1	1
	2003	43	20	28	19	9	21
Biennial forbs	2000	4	0	5	0	0	9
	2001	1	1	1	0	1	1
	2002	0	0	0	0	0	0
	2003	0	0	1	0	0	0
Annual forbs	2000	0	0	0	0	0	0
	2001	4	8	1	0	0	3
	2002	0	0	0	0	0	0
	2003	33	14	4	3	3	15

At the knapweed site after four years, root weevils and root moths were observed in both control and treatment plots and, therefore, effects of this treatment could not be determined. However, knapweed biomass decreased to near zero in the third year and began increasing again in the fourth year. The decline may have been due to drought, root-feeding insects, or both. Changes in biomass with seeding, sugar application, and inoculation at the knapweed site are shown in Tables 15, 16, and 17, respectively.

Total biomass was not very different between seeded and unseeded plots (Table 15). With seeding of native and introduced perennial grasses, there was a 49% increase in perennial grasses. On average, knapweed was 35% lower in seeded plots over unseeded plots. Biennial forbs were 138% higher in seeded plots over unseeded plots.

Table 15. Effect of seeding on vegetation total aboveground biomass (g/m^2) at the knapweed site at Fort Carson.

Species	Year	Bug	Bug/ seed	Bug/ sugar	Bug/ sugar/ seed	Bug/ sugar/ soil	Bug/ sugar/soil /seed
Total	2000	126	109	95	80	93	75
	2001	124	153	107	95	109	121
	2002	14	13	10	8	9	7
	2003	149	170	131	102	135	175
Knapweed	2000	29	29	52	26	24	38
	2001	48	64	64	27	39	51
	2002	0	0	1	0	1	0
	2003	3	0	7	2	3	1
Shrubs	2000	33	34	14	5	8	0
	2001	12	15	2	6	4	16
	2002	7	4	2	1	0	0
	2003	13	19	5	3	2	5
Perennial grasses	2000	25	15	6	28	32	16
	2001	31	37	22	44	50	37
	2002	5	7	5	5	6	6
	2003	68	85	48	70	62	96
Annual grasses	2000	5	2	0	0	0	0
	2001	3	5	0	0	3	1
	2002	0	0	0	0	0	0
	2003	2	6	5	0	14	1
Perennial forbs	2000	13	8	6	8	7	5
	2001	28	19	17	15	9	11
	2002	2	2	2	2	1	1
	2003	29	24	29	13	20	38
Biennial forbs	2000	21	20	17	13	21	16
	2001	1	11	1	3	2	6
	2002	0	0	0	0	0	0
	2003	1	1	1	2	4	2
Annual forbs	2000	0	0	0	0	0	0
	2001	2	2	0	0	2	0
	2002	0	0	0	0	0	0
	2003	33	34	37	12	30	32

After four years of sugar application at the knapweed site, total aboveground biomass was lower in plots with sugar application than in plots without sugar application. The biomass of perennial forbs decreased 18%, while succulents decreased 61% (Table 16). No consistent change was seen in biomass of knapweed, biennial forbs, and perennial grasses.

Table 16. Effect of sugar application on vegetation total aboveground biomass (g/m^2) at the knapweed site at Fort Carson.

Species	Year	Bug	Bug/ sugar	Bug/ seed	Bug/ seed/ sugar	Bug/ seed/ soil	Bug/ seed/soil/ sugar
Total above-ground biomass	2000	126	95	109	80	87	75
	2001	124	107	153	95	119	121
	2002	14	10	13	8	27	7
	2003	149	131	170	102	145	175
Knapweed	2000	29	52	29	26	21	38
	2001	48	64	64	27	48	51
	2002	0	1	0	0	1	0
	2003	3	7	0	2	9	1
Shrubs	2000	33	14	34	5	20	0
	2001	12	2	15	6	13	16
	2002	7	2	4	1	19	0
	2003	13	5	19	3	5	5
Perennial grasses	2000	25	6	15	28	22	16
	2001	31	22	37	44	39	37
	2002	5	5	7	5	5	6
	2003	68	48	85	70	66	96
Annual grasses	2000	5	0	2	0	2	0
	2001	3	0	5	0	4	1
	2002	0	0	0	0	0	0
	2003	2	5	6	0	7	1
Perennial forbs	2000	13	6	8	8	6	5
	2001	28	17	19	15	13	11
	2002	2	2	2	2	2	1
	2003	29	29	24	13	25	38
Biennial forbs	2000	21	17	20	13	16	16
	2001	1	1	11	3	1	6
	2002	0	0	0	0	0	0
	2003	1	1	1	2	3	2
Annual forbs	2000	0	0	0	0	0	0
	2001	2	0	2	0	1	0
	2002	0	0	0	0	0	0
	2003	33	37	34	12	31	32

No consistent changes were measured in any vegetation type when plots were inoculated with native soil (Table 17). Soil inoculation should theoretically introduce native bacteria and mycorrhizal fungi into a disturbed community. This provides an added benefit to vegetation species that support mycorrhizal fungi, primarily perennial grasses and shrubs. However, no effects were seen in this study.

Table 17. Effect of soil inoculation on vegetation total aboveground biomass (g/m^2) at the knapweed site at Fort Carson.

Species	Year	Bug/ seed	Bug/ seed/ soil	Bug/ sugar	Bug/ sugar/ soil	Bug/ seed/ sugar	Bug/ seed/ sugar/soil
Total	2000	109	87	95	93	80	75
	2001	153	119	107	109	95	121
	2002	13	27	10	9	8	7
	2003	170	145	131	135	102	175
Knapweed	2000	29	21	52	24	26	38
	2001	64	48	64	39	27	51
	2002	0	1	1	1	0	0
	2003	0	9	7	3	2	1
Shrubs	2000	34	20	14	8	5	0
	2001	15	13	2	4	6	16
	2002	4	19	2	0	1	0
	2003	19	5	5	2	3	5
Perennial grasses	2000	15	22	6	32	28	16
	2001	37	39	22	50	44	37
	2002	7	5	5	6	5	6
	2003	85	66	48	62	70	96
Annual grasses	2000	2	2	0	0	0	0
	2001	5	4	0	3	0	1
	2002	0	0	0	0	0	0
	2003	6	7	5	14	0	1
Perennial forbs	2000	8	6	6	7	8	5
	2001	19	13	17	9	15	11
	2002	2	2	2	1	2	1
	2003	24	25	29	20	13	38
Biennial forbs	2000	20	16	17	21	13	16
	2001	11	1	1	2	3	6
	2002	0	0	0	0	0	0
	2003	1	3	1	4	2	2
Annual forbs	2000	0	0	0	0	0	0
	2001	2	1	0	2	0	0
	2002	0	0	0	0	0	0
	2003	34	31	37	30	12	32

6.0 SIMULATION RESULTS

The Fort Carson experimental design consisted of ten replications of eight treatment combinations, for a total of 80 experimental plots (40 at the brome site and 40 at the knapweed site). Each of these 80 plots was included in the EDYS application. Initial biomass values for plant species were based on the 2000 biomass data supplied by Colorado State University. EDYS then simulated the dynamics of each of these 80 plots over a four-year time period based on 1) the precipitation values received during the period of simulation, 2) the experimental treatments imposed on each plot, and 3) no livestock grazing or military training on the plots. The simulated values were then compared plot-by-plot to their values from the 2001, 2002, and 2003 sampling. The primary purpose of comparing simulation results to experimental results is to verify that the modelling results are reasonable and to establish a level of accuracy for these results. The purpose of the simulation modelling itself is to provide a tool that can be used in land-management decision making to estimate the responses of the target variables to various management scenarios over time.

The vegetation parameter used to evaluate these management scenarios was end-of-growing season aboveground biomass (g/m^2) clipped in June of each year. For shrubs, the value was clippable aboveground biomass (stems and leaves), which is approximately one-half of total aboveground biomass. For grasses and forbs, it was total aboveground biomass.

6.1 Brome Community

6.1.1 Community-Wide Accuracy

EDYS was parameterized for the brome community, for each of the different plot-level treatments, and run for four years (Table 18), using initial conditions. As in the field experiments, total biomass decreased in Year 3. Japanese brome decreased in Year 3 as well and then began to increase in Year 4.

Simulation values were compared to field-collected aboveground biomass data for all 40 plots for each of the four years (Table 19). Values were compared for total biomass (sum of all species) and major species, including Japanese brome, bindweed, western wheatgrass, and green needlegrass.

Table 18. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site and a four-year simulation run. Numbers shown are means of eight different treatments with five replications each.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	128.7	177.5	134.3	84.5	198.9
Twistspine pricklypear	0.5	0.6	0.1	0.2	0.4
Soapweed	0.0	0.1	0.2	0.4	1.2
Crested wheatgrass	0.0	1.7	2.1	2.7	7.3
Western wheatgrass	32.2	36.0	27.0	25.2	75.3
Purple threeawn	0.1	0.5	0.6	0.5	0.9
Sideoats grama	0.0	0.1	0.2	0.5	1.1
Blue grama	0.0	0.1	0.5	0.5	0.7
Kentucky bluegrass	0.2	0.3	0.2	0.3	0.6
Little bluestem	0.0	0.2	0.3	0.4	1.0
Sacaton	0.0	0.2	0.3	0.8	2.1
Sand dropseed	0.0	1.3	0.6	0.7	1.1
Green needlegrass	36.5	19.7	3.5	4.5	6.4
Ragweed	0.0	0.9	1.5	2.6	3.2
Spotted knapweed	0.0	1.0	1.6	1.1	3.2
Canada thistle	2.2	7.2	5.0	5.2	12.7
Bindweed	21.8	31.4	12.1	11.0	10.8
Scarlet beeblossum	3.3	2.3	1.3	1.4	1.9
Golden aster	0.1	1.1	0.5	0.9	2.1
Hoarhound	2.3	1.7	0.5	0.5	0.8
Alfalfa	0.0	0.2	0.3	0.5	1.2
Orange globemallow	0.1	6.2	1.2	1.9	3.2
Mignonette	21.8	21.0	3.1	1.6	5.1
Wavyleaf thistle	2.7	1.5	2.3	2.0	5.2
Sweetclover	0.2	1.7	8.3	1.4	8.6
Japanese brome	4.3	38.8	59.7	17.1	41.7
Lambsquarters	0.1	0.2	0.1	0.1	0.2
Sunflower	0.0	0.3	0.3	0.1	0.2
Bladderpod	0.1	0.7	0.5	0.2	0.4
Russian thistle	0.0	0.4	0.4	0.3	0.4
Tansymustard	0.3	18.4	1.9	25.7	28.2
Litter	137.8	175.8	46.8	213.3	261.2

The dominant species overall were Japanese brome, bindweed, western wheatgrass, and green needlegrass. Mean accuracy for the four years was 40% for Japanese brome, 44% for bindweed, 57% for western wheatgrass, 66% for needlegrass, and 52% for total aboveground biomass. Accuracies were high for most species in Year 1, but lower in subsequent years. Results in Year 3, the year that the drought occurred, were low, perhaps because adequate on-site precipitation data was not available.

Table 19. Percent accuracy for the four-year modelling run for the Fort Carson brome site. Numbers shown for predicted and sampled are means of eight treatments with five replications each.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	38.77	38.71	0.999
2001	59.74	25.78	0.432
2002	17.07	0.03	0.002
2003	41.69	6.93	0.166
Bindweed			
2000	31.40	30.14	0.960
2001	12.14	49.90	0.243
2002	11.04	4.58	0.415
2003	10.83	86.38	0.125
Western wheatgrass			
2000	35.98	27.85	0.774
2001	26.95	30.40	0.887
2002	25.15	1.65	0.065
2003	75.26	42.55	0.565
Green needlegrass			
2000	19.68	19.29	0.980
2001	3.46	16.30	0.212
2002	4.50	2.56	0.569
2003	6.36	5.50	0.864
Total			
2000	177.45	98.90	0.557
2001	134.29	102.75	0.765
2002	84.46	8.67	0.103
2003	198.92	130.33	0.655

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

The 95% confidence intervals of the population means of each of the composite variables were calculated for the 2000 to 2004 sampled values. These intervals give the statistical ranges for the means of each variable that are the best statistical estimates of the true value of that mean. As such, they are a measurement of the sample accuracy for that variable. These values were then compared to the 95% confidence intervals of the EDYS predicted values for the variables. The 95% confidence intervals of the actual and EDYS results overlap for 25% of the comparisons (Figure 6), indicating that the EDYS simulation was not very accurate.

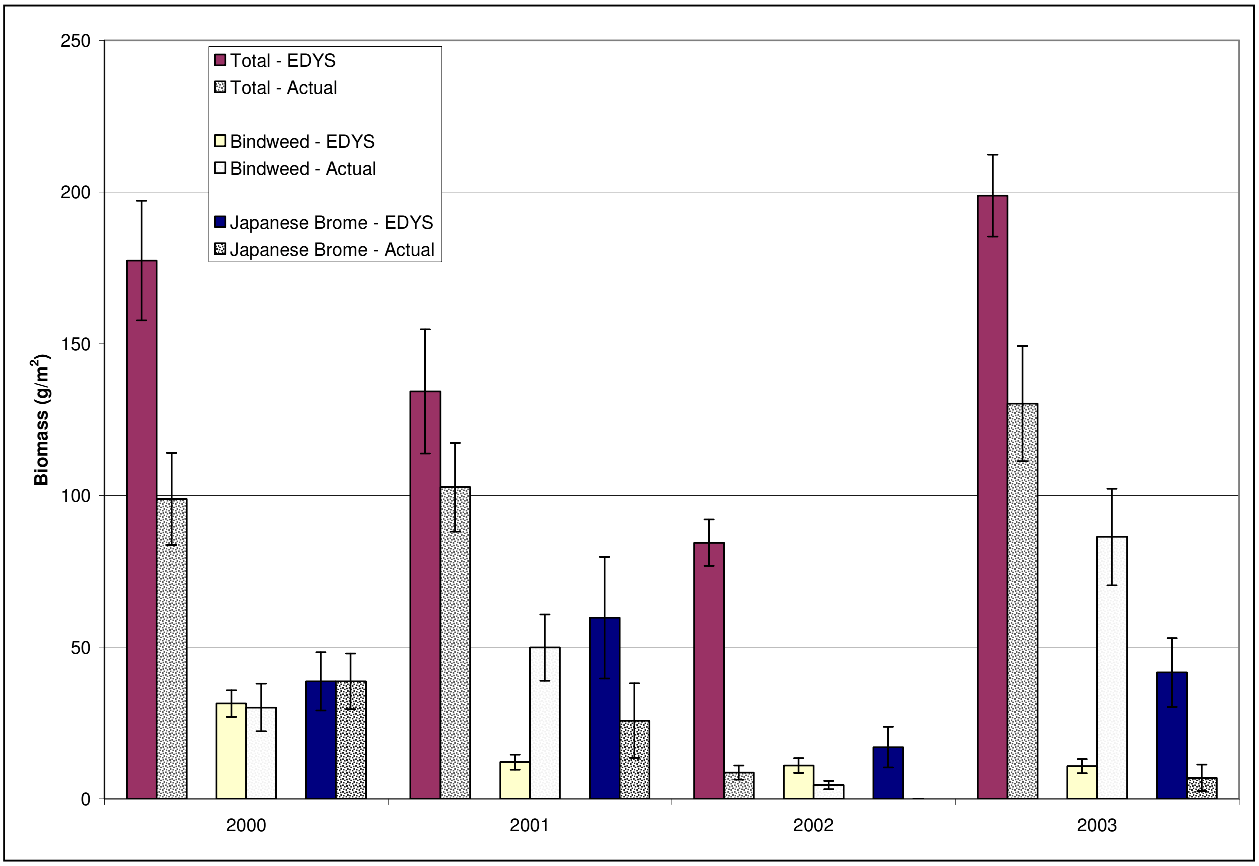

Figure 6. Comparison of aboveground biomass values (g/m^2) between actual and EDYS simulation results for the Fort Carson brome site.

6.1.2 Baseline Conditions (Control)

Baseline conditions were defined as the vegetation changes that would occur in the absence of further human impacts such as seeding, cattle grazing, military training, or prescribed burning. The initial conditions were those typical of present conditions. The simulation runs were for 4 and 50 years. In the four-year simulation, total biomass increased from Year 1 to Year 2 and then decreased in Year 3, similar to results measured in experimental plots, most likely due to drought (Table 20). Japanese brome increased in Year 2 and decreased in Year 3, the year of low rainfall. Bindweed biomass increased a great deal in 2003, while Japanese brome had very low production.

Table 20. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, under baseline conditions (i.e., no burning, no seeding, no sugar application, and no inoculation) and a four-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	19.9	86.2	236.5	112.4	160.4
Twistspine pricklypear	0.0	0.0	0.0	0.2	0.7
Soapweed	0.0	0.0	0.1	0.7	1.9
Crested wheatgrass	0.0	0.0	0.2	0.5	1.1
Western wheatgrass	0.0	0.1	0.7	1.7	4.1
Purple threeawn	0.0	0.1	0.9	1.2	1.3
Sideoats grama	0.0	0.0	0.3	1.3	2.7
Blue grama	0.0	0.1	0.5	0.7	0.9
Kentucky bluegrass	0.0	0.0	0.3	0.8	1.3
Little bluestem	0.0	0.0	0.6	1.4	2.2
Sacaton	0.0	0.0	0.5	2.6	6.0
Sand dropseed	0.0	0.1	0.9	1.6	1.8
Green needlegrass	0.0	0.0	0.1	0.3	0.5
Ragweed	0.0	0.4	3.9	9.8	10.3
Spotted knapweed	0.0	0.3	0.5	0.2	0.3
Canada thistle	0.0	0.1	0.5	1.0	1.6
Bindweed	12.4	22.8	30.7	28.1	26.3
Scarlet beeblossum	1.1	1.2	2.0	2.7	3.1
Golden aster	0.0	0.0	0.3	1.3	3.0
Hoarhound	0.3	0.6	1.1	0.8	1.2
Alfalfa	0.0	0.1	0.4	0.7	1.3
Orange globemallow	0.0	0.8	3.6	8.4	12.7
Mignonette	1.8	2.5	1.9	0.9	0.4
Wavyleaf thistle	0.0	0.2	1.0	2.5	4.1
Sweetclover	1.4	1.9	1.5	0.7	0.3
Japanese brome	1.6	52.6	180.4	40.5	69.8
Lambsquarters	0.1	0.2	0.2	0.2	0.2
Sunflower	0.0	0.3	0.5	0.2	0.2
Bladderpod	0.4	1.1	1.3	0.4	0.3
Russian thistle	0.0	0.6	1.3	0.7	0.7
Tansymustard	0.7	0.4	0.3	0.2	0.2
Litter	99.4	102.8	242.4	389.2	418.7

The results of the EDYS simulations for the first year at the brome site control plots (no burn, no seed, no sugar, no inoculation) were similar to the field results in the first two years (Table 21). Because of the problems with modelling the plant responses in the third year, accuracy was low. Average accuracy was 32% for Japanese brome, 49% for bindweed, and 56% for total aboveground biomass for the four years. Western wheatgrass and green needlegrass were not significant in the control plots.

One possible reason for the low accuracy in the third and fourth years was the lack of accurate precipitation data for the study area. The trend of increasing Japanese brome production in 2001 and a subsequent decrease in 2003 and 2003 was correctly simulated by EDYS but the magnitude of the decline was incorrect. However, the extent of the biomass decline was not well simulated. Perhaps the actual precipitation values of the study area were lower than the values that were used in the EDYS simulation. Because Japanese brome decline in 2003 was not well estimated, the increase in bindweed was also not well estimated. However, the total production for this year corresponded well with sampled data.

Table 21. Percent accuracy for the four-year modelling run for the Fort Carson brome site under baseline conditions (i.e., no burning, no seeding, no sugar application, and no inoculation).

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	52.56	85.76	0.613
2001	180.38	113.96	0.632
2002	40.47	0.10	0.002
2003	69.83	1.80	0.026
Bindweed			
2000	22.78	33.10	0.688
2001	30.74	36.20	0.849
2002	28.06	6.22	0.222
2003	26.35	137.36	0.192
Total			
2000	86.20	135.57	0.636
2001	236.49	166.27	0.703
2002	112.43	10.60	0.094
2003	160.40	152.85	0.953

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

In the 50-year EDYS simulation, western wheatgrass was the dominant species at the end of 50 years (Table 22). The combined biomass of twistspine pricklypear and soapweed was about equal to that of western wheatgrass at Year 50. Biomass of Japanese brome was zero by Year 20 and bindweed was very at this time and stayed that way until the end of the simulation. The decline in Japanese brome and the increase in perennial species is in agreement with studies of succession providing no disturbance occurs in the area (McLendon and Redente 1992, 1994).

Table 22. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, under baseline conditions (i.e., no burning, no seeding, no sugar application, and no inoculation) and a 50-year simulation run.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	86	396	697	974	1175	1214
Twistspine pricklypear	0	0	5	28	113	249	249
Soapweed	0	0	19	117	253	250	250
Crested wheatgrass	0	0	9	19	24	32	40
Western wheatgrass	0	0	99	317	393	466	508
Purple threeawn	0	0	2	1	1	0	0
Sideoats grama	0	0	16	26	29	38	43
Blue grama	0	0	1	1	0	0	0
Kentucky bluegrass	0	0	5	4	2	1	1
Little bluestem	0	0	5	4	3	2	2
Sacaton	0	0	65	70	50	34	15
Sand dropseed	0	0	3	1	1	0	0
Green needlegrass	0	0	2	3	3	3	3
Ragweed	0	0	7	3	2	2	1
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	0	0	9	7	8	7	7
Bindweed	12	23	9	1	0	0	0
Scarlet beeblossum	1	1	5	3	2	1	1
Golden aster	0	0	35	46	39	32	25
Hoarhound	0	1	2	1	1	1	1
Alfalfa	0	0	3	2	2	1	1
Orange globemallow	0	1	21	3	1	1	1
Mignonette	2	2	0	0	0	0	0
Wavyleaf thistle	0	0	32	39	47	51	64
Sweetclover	1	2	0	0	0	0	0
Japanese brome	2	53	40	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0
Litter	99	103	165	145	193	182	208

6.1.3 Prescribed Burning

The simulated prescribed fire scenario burned 35 of the 40 cells at the brome site in Year 1. The prescribed fire scenario for the burn was that every cell was exposed to the fire (i.e., every cell edge was "torched"), whether or not the specific cell burned was dependent on its fuel load. For the prescribed burn simulation, all plots were burned (except the control plots) in October, 2000.

A four-year simulation was completed that included prescribed burning in the first year (Table 23). Japanese brome actually increased in the year following the burn, as it did in the experimental plots. This may have occurred because the fire was not hot enough to decimate the seed bank, but it did remove perennial grass and forb aboveground biomass, giving Japanese brome a competitive advantage. However, in 2002, Japanese brome production dropped to zero, which was not well represented by EDYS. In 2004, there was an increase in Japanese brome production but this was over-estimated by EDYS. Again, the reason may be that realistic precipitation data was not available.

Table 23. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning and a four-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	116.4	158.6	136.9	71.7	226.2
Twistspine pricklypear	0.0	0.0	0.0	0.1	0.4
Soapweed	0.0	0.1	0.3	0.6	1.8
Crested wheatgrass	0.0	0.1	0.2	0.3	0.8
Western wheatgrass	9.7	13.0	14.2	18.1	51.9
Purple threeawn	0.0	0.7	0.9	0.5	1.1
Sideoats grama	0.0	0.1	0.2	0.6	2.1
Blue grama	0.0	0.2	0.2	0.3	0.5
Kentucky bluegrass	0.0	0.1	0.2	0.3	0.7
Little bluestem	0.0	0.3	0.3	0.2	0.8
Sacaton	0.0	0.2	0.3	0.8	3.7
Sand dropseed	0.0	0.4	0.5	0.4	1.0
Green needlegrass	15.2	8.6	1.5	2.3	3.4
Ragweed	0.0	1.2	1.9	2.9	4.3
Spotted knapweed	0.0	0.3	0.3	0.2	0.3
Canada thistle	4.3	6.6	11.4	7.9	23.8
Bindweed	22.2	36.8	10.4	8.0	8.5
Scarlet beeblossum	7.2	6.7	3.4	2.9	4.0
Golden aster	0.0	0.1	0.2	0.6	1.9
Hoarhound	5.7	5.6	1.2	0.9	1.4
Alfalfa	0.0	0.1	0.2	0.3	0.9
Orange globemallow	0.0	0.7	1.0	1.5	3.8
Mignonette	36.1	44.3	1.1	0.2	0.2
Wavyleaf thistle	14.5	19.8	20.7	11.2	39.3
Sweetclover	0.1	0.4	0.3	0.1	0.2
Japanese brome	0.8	10.1	64.3	9.8	67.6
Lambsquarters	0.4	0.3	0.2	0.1	0.2
Sunflower	0.0	0.3	0.3	0.1	0.3
Bladderpod	0.1	0.8	0.6	0.1	0.5
Russian thistle	0.0	0.6	0.6	0.5	0.6
Tansymustard	0.1	0.2	0.2	0.1	0.2
Litter	102.1	145.8	14.0	204.9	224.7

Accuracy was again low in the third year, causing average accuracy for the four-year period to be low for each species (Table 24). Average accuracy was 25% for Japanese brome, 33% for bindweed, 50% for western wheatgrass, 36% for green needlegrass, and 63% for total aboveground biomass.

Table 24. Percent accuracy for the four-year modelling run for the Fort Carson brome site with prescribed burning.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	10.07	24.82	0.406
2001	64.26	29.91	0.465
2002	9.83	0.00	0.000
2003	67.64	8.01	0.118
Bindweed			
2000	36.79	19.84	0.539
2001	10.41	39.05	0.267
2002	8.01	3.43	0.428
2003	8.47	96.55	0.088
Western wheatgrass			
2000	13.03	16.26	0.801
2001	14.19	36.78	0.386
2002	18.06	1.17	0.065
2003	51.90	39.00	0.751
Green needlegrass			
2000	8.57	24.09	0.356
2001	1.51	21.69	0.070
2002	2.26	4.04	0.559
2003	3.36	7.45	0.451
Total			
2000	158.58	135.57	0.855
2001	136.94	166.27	0.824
2002	71.67	10.60	0.148
2003	226.17	152.85	0.676

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

At the end of the 50-year simulation with a prescribed burn in the first year, western wheatgrass was the dominant species (Table 26). Soapweed and twistspine pricklypear were the second-most abundant species and brome and bindweed had negligible biomass. These results are similar to those obtained in the 50-year simulation of the control treatment, indicating that burning for a single year does not have substantial long-term effects on the total production of this community. However, the burning treatment reduced the production of western wheatgrass by 20% when compared to the control plots. Some perennial forbs, like Canada thistle, gained dominance in the long-term simulation, but this was likely due to the higher initial biomass of this species in the plots that were burned.

Table 26. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	116	160	420	671	815	984	1130
Twistspine pricklypear	0	0	3	11	38	112	203
Soapweed	0	0	8	42	112	163	239
Crested wheatgrass	0	0	5	9	11	12	12
Western wheatgrass	10	13	182	347	396	426	402
Purple threeawn	0	1	1	0	0	0	0
Sideoats grama	0	0	9	15	16	19	21
Blue grama	0	0	1	0	0	0	0
Kentucky bluegrass	0	0	2	2	2	1	1
Little bluestem	0	0	1	1	1	1	1
Sacaton	0	0	23	25	17	12	6
Sand dropseed	0	0	1	1	0	0	0
Green needlegrass	15	9	7	8	8	8	9
Ragweed	0	1	2	2	1	1	1
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	4	7	56	89	99	111	120
Bindweed	22	37	2	0	0	0	0
Scarlet beeblossum	7	7	4	2	1	1	0
Golden aster	0	0	17	24	21	21	19
Hoarhound	6	6	1	1	1	1	1
Alfalfa	0	0	2	1	1	1	0
Orange globemallow	0	1	5	1	0	0	0
Mignonette	36	45	0	0	0	0	0
Wavyleaf thistle	15	20	71	89	88	93	95
Sweetclover	0	0	0	0	0	0	0
Japanese brome	1	10	15	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	102	146	169	153	189	168	204

6.1.4 Treatment Combinations

When prescribed burning and seeding of perennial species were included in the same four-year simulation, Japanese brome was the dominant species at the end of the run (Table 27). In the year following the prescribed burn, biomass of Japanese brome increased, although total biomass decreased. In the third year when precipitation was only half of normal, both total biomass and Japanese brome decreased. Western wheatgrass steadily increased from Year 1 to Year 4 and was second only to brome at the end of the simulation.

Table 27. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding and a four-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	108.5	121.1	105.1	69.0	200.1
Twistspine pricklypear	0.0	0.0	0.0	0.1	0.4
Soapweed	0.0	0.1	0.3	0.4	1.5
Crested wheatgrass	0.0	0.1	0.6	1.0	1.7
Western wheatgrass	5.9	8.0	9.6	20.5	62.9
Purple threeawn	0.6	0.9	1.5	0.6	1.3
Sideoats grama	0.2	0.2	0.5	1.1	2.6
Blue grama	0.0	0.2	1.1	1.1	1.2
Kentucky bluegrass	0.0	0.1	0.2	0.2	0.5
Little bluestem	0.0	0.4	0.4	0.2	0.6
Sacaton	0.0	0.2	0.5	0.9	2.6
Sand dropseed	0.0	0.4	0.8	0.6	1.2
Green needlegrass	46.2	26.2	4.7	7.0	10.3
Ragweed	0.1	1.4	3.1	4.4	5.2
Spotted knapweed	0.0	0.3	0.4	0.2	0.3
Canada thistle	0.1	0.3	0.5	0.9	2.1
Bindweed	12.6	21.2	7.1	8.0	8.1
Scarlet beeblossum	3.1	2.9	1.7	1.7	2.1
Golden aster	0.4	1.5	1.5	3.1	7.1
Hoarhound	1.8	2.0	0.7	0.6	1.0
Alfalfa	0.0	0.1	0.4	0.6	1.3
Orange globemallow	0.1	0.9	1.7	2.9	5.1
Mignonette	35.8	41.5	0.9	0.1	0.3
Wavyleaf thistle	0.2	0.5	1.1	3.3	7.2
Sweetclover	0.3	0.6	0.3	0.1	0.2
Japanese brome	0.7	8.7	63.4	8.6	71.1
Lambsquarters	0.1	0.2	0.2	0.2	0.2
Sunflower	0.0	0.3	0.3	0.1	0.3
Bladderpod	0.1	0.9	0.7	0.1	0.6
Russian thistle	0.0	0.6	0.6	0.6	0.8
Tansymustard	0.1	0.2	0.2	0.1	0.2
Litter	150.8	194.7	14.1	204.1	258.0

Average accuracy for these plots was 11% for Japanese brome, 27% for bindweed, 40% for western wheatgrass, 62% for green needlegrass, and 62% for total aboveground biomass (Table 28). In the field, Japanese brome production declined drastically in 2002. This decline also occurred in the control and burning treatments. Again, this dramatic decline was not well represented by the EDYS simulations.

Table 28. Percent accuracy for the four-year modelling run for the Fort Carson brome site with prescribed burning, and seeding.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	8.67	37.77	0.229
2001	63.43	9.67	0.152
2002	8.60	0.02	0.002
2003	71.13	3.20	0.045
Bindweed			
2000	21.15	14.70	0.695
2001	7.09	49.24	0.144
2002	8.03	1.08	0.134
2003	8.11	81.2	0.100
Western wheatgrass			
2000	8.03	9.91	0.810
2001	9.55	16.24	0.588
2002	20.46	0.73	0.036
2003	62.86	9.71	0.154
Green needlegrass			
2000	26.20	30.66	0.855
2001	4.69	36.73	0.128
2002	7.02	3.44	0.490
2003	10.26	10.28	0.998
Total			
2000	121.14	158.36	0.765
2001	105.08	163.9	0.641
2002	69.04	11.62	0.168
2003	200.06	182.55	0.912

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Western wheatgrass was the dominant species at the end of the 50-year simulation which included burning and seeding, followed by soapweed and twistspine pricklypear (Table 29). In this simulation, western wheatgrass had 43% more biomass than in the burning only simulation. The change was due to the seeding of this species. Japanese brome and bindweed had very little biomass after 50 years and very little annual forbs were present as well.

Table 29. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	**Year 1**	**Year 10**	**Year 20**	**Year 30**	**Year 40**	**Year 50**
Total	108	121	432	710	865	1013	1150
Twistspine pricklypear	0	0	2	8	26	79	169
Soapweed	0	0	5	23	80	145	239
Crested wheatgrass	0	0	5	7	6	6	5
Western wheatgrass	6	8	313	548	617	627	572
Purple threeawn	1	1	1	2	2	2	2
Sideoats grama	0	0	11	22	28	40	50
Blue grama	0	0	1	1	0	0	0
Kentucky bluegrass	0	0	1	1	0	0	0
Little bluestem	0	0	1	1	1	1	0
Sacaton	0	0	7	6	4	3	2
Sand dropseed	0	0	1	0	0	0	0
Green needlegrass	46	26	17	17	18	18	18
Ragweed	0	1	3	2	2	1	1
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	0	0	5	5	6	9	10
Bindweed	13	21	2	0	0	0	0
Scarlet beeblossum	3	3	2	1	1	0	0
Golden aster	0	2	27	32	29	26	20
Hoarhound	2	2	1	1	1	0	0
Alfalfa	0	0	1	1	1	0	0
Orange globemallow	0	1	3	1	0	0	0
Mignonette	36	42	0	0	0	0	0
Wavyleaf thistle	0	1	22	31	42	52	58
Sweetclover	0	1	0	0	0	0	0
Japanese brome	1	9	1	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	151	195	166	148	182	157	197

At the end of the four-year simulation that included burning and sugar application, biomass of western wheatgrass was slightly higher than Japanese brome (Table 30). Contrary to the simulation with burning alone, brome decreased in the year following the prescribed burn. Brome decreased again in Year 3 and increased in the Year 4. Bindweed biomass declined after the first year.

Table 30. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, sugar application and a four-year simulation run.

Species	June Aboveground Biomass (g/m²)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	157.9	197.2	70.9	85.5	185.7
Twistspine pricklypear	0.2	0.2	0.0	0.2	0.4
Soapweed	0.0	0.1	0.1	0.6	1.5
Crested wheatgrass	0.0	0.1	0.2	0.3	0.6
Western wheatgrass	6.8	9.1	6.2	14.9	50.1
Purple threeawn	0.0	0.7	0.6	0.6	1.1
Sideoats grama	0.0	0.1	0.2	0.5	1.0
Blue grama	0.0	0.2	0.2	0.3	0.4
Kentucky bluegrass	0.0	0.1	0.2	0.2	0.4
Little bluestem	0.0	0.3	0.3	0.3	0.6
Sacaton	0.0	0.2	0.3	0.7	1.8
Sand dropseed	0.0	0.3	0.4	0.4	0.8
Green needlegrass	78.1	44.1	7.5	10.3	14.0
Ragweed	0.0	1.2	0.9	1.8	2.7
Spotted knapweed	0.0	0.2	0.3	0.2	0.3
Canada thistle	2.7	4.3	7.2	14.7	33.6
Bindweed	21.8	36.0	9.9	11.7	11.1
Scarlet beeblossum	5.6	5.2	2.3	2.6	3.2
Golden aster	0.2	0.8	0.4	1.3	2.6
Hoarhound	1.7	1.8	0.6	0.6	0.9
Alfalfa	0.0	0.1	0.2	0.3	0.6
Orange globemallow	0.5	1.4	1.5	1.8	3.5
Mignonette	34.4	36.0	0.4	0.2	0.3
Wavyleaf thistle	0.1	0.3	0.4	1.1	2.5
Sweetclover	0.0	0.3	0.2	0.2	0.2
Japanese brome	5.2	52.0	28.7	19.2	49.4
Lambsquarters	0.1	0.2	0.1	0.1	0.2
Sunflower	0.0	0.2	0.2	0.1	0.3
Bladderpod	0.1	0.9	0.7	0.2	0.5
Russian thistle	0.1	0.5	0.3	0.2	0.5
Tansymustard	0.4	0.3	0.1	0.1	0.2
Litter	95.2	157.6	12.6	154.4	231.1

Accuracy for Japanese brome and western wheatgrass decreased in Year 3 in this simulation, but was fairly high for bindweed, green needlegrass, and total aboveground biomass (Table 31). Average accuracy was 30% for Japanese brome, 44% for bindweed, 39% for western wheatgrass, 59% for green needlegrass, and 62% for total aboveground biomass.

Table 31. Percent accuracy for the four-year modelling run for the Fort Carson brome site with prescribed burning, and sugar application.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	51.99	37.53	0.722
2001	28.72	8.69	0.303
2002	19.20	0.00	0.000
2003	49.44	7.67	0.155
Bindweed			
2000	36.00	38.74	0.929
2001	9.94	59.78	0.166
2002	11.66	6.26	0.537
2003	11.11	96.12	0.116
Western wheatgrass			
2000	9.12	14.45	0.631
2001	6.20	10.62	0.584
2002	14.92	0.45	0.030
2003	50.09	16.43	0.328
Green needlegrass			
2000	44.11	31.08	0.705
2001	7.52	14.82	0.507
2002	10.27	5.39	0.525
2003	14.00	8.97	0.641
Total			
2000	197.24	164.17	0.832
2001	70.90	125.75	0.564
2002	85.50	18.35	0.215
2003	185.73	162.20	0.873

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Total biomass steadily increased over the 50-year simulation that included a prescribed burn and sugar application (Table 32). At the end of the 50 years, western wheatgrass was the dominant species, followed by soapweed and twistspine pricklypear. Japanese brome and bindweed disappeared by Year 20, as did most annuals.

Table 32. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, sugar application and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	158	197	427	705	899	1039	1166
Twistspine pricklypear	0	0	2	14	65	97	182
Soapweed	0	0	6	30	95	175	239
Crested wheatgrass	0	0	3	6	6	7	6
Western wheatgrass	7	9	244	466	531	556	527
Purple threeawn	0	1	1	0	0	0	0
Sideoats grama	0	0	4	7	7	10	10
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	1	1	0	0	0
Little bluestem	0	0	1	1	1	1	1
Sacaton	0	0	12	13	9	6	2
Sand dropseed	0	0	1	0	0	0	0
Green needlegrass	78	44	26	27	29	29	29
Ragweed	0	1	1	1	1	1	1
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	3	4	77	93	104	100	101
Bindweed	22	36	3	0	0	0	0
Scarlet beeblossum	6	5	3	2	1	0	0
Golden aster	0	1	14	21	19	18	14
Hoarhound	2	2	1	1	1	0	1
Alfalfa	0	0	1	1	1	1	0
Orange globemallow	0	1	3	1	0	0	0
Mignonette	34	36	0	0	0	0	0
Wavyleaf thistle	0	0	12	20	27	38	50
Sweetclover	0	0	0	0	0	0	0
Japanese brome	5	52	10	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	95	158	165	150	185	159	202

Western wheatgrass was the dominant species and had twice as much biomass as Japanese brome at the end of the four-year simulation including burning, seeding, and sugar application (Table 33). Both seeding and sugar should favor perennial grasses over annual grasses. Japanese brome decreased slightly in the year following the burn and decreased quite a bit in the drought year (third year) as well. Bindweed was much lower in the year following the burn and stayed low throughout the simulation.

Table 33. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding, sugar application and a four-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	191.1	246.7	126.5	80.5	218.5
Twistspine pricklypear	4.2	4.6	0.6	0.7	1.1
Soapweed	0.0	0.0	0.1	0.3	1.1
Crested wheatgrass	0.0	0.1	0.4	0.5	1.0
Western wheatgrass	71.3	78.9	52.5	43.0	123.5
Purple threeawn	0.0	0.4	0.4	0.1	0.5
Sideoats grama	0.0	0.1	0.1	0.2	0.7
Blue grama	0.0	0.1	0.7	0.6	0.7
Kentucky bluegrass	0.0	0.1	0.1	0.1	0.3
Little bluestem	0.0	0.2	0.2	0.1	0.3
Sacaton	0.0	0.1	0.3	0.4	1.3
Sand dropseed	0.0	0.2	0.3	0.2	0.5
Green needlegrass	45.7	25.4	3.9	4.2	6.1
Ragweed	0.2	0.8	0.7	0.8	1.5
Spotted knapweed	0.0	0.1	0.2	0.1	0.2
Canada thistle	2.1	2.7	4.6	5.2	14.9
Bindweed	23.2	34.2	9.4	8.4	8.6
Scarlet beeblossum	4.2	3.8	1.7	1.7	2.2
Golden aster	0.1	0.2	0.2	0.4	1.2
Hoarhound	2.5	2.4	0.5	0.5	0.8
Alfalfa	0.0	0.1	0.3	0.4	0.7
Orange globemallow	0.1	0.4	0.5	0.4	1.1
Mignonette	25.3	23.4	0.3	0.1	0.2
Wavyleaf thistle	0.0	0.1	0.2	0.2	0.6
Sweetclover	0.0	0.1	0.2	0.0	0.2
Japanese brome	12.1	67.2	47.3	11.2	47.9
Lambsquarters	0.1	0.1	0.1	0.1	0.2
Sunflower	0.0	0.2	0.1	0.0	0.2
Bladderpod	0.1	0.4	0.4	0.0	0.3
Russian thistle	0.0	0.2	0.2	0.1	0.4
Tansymustard	0.1	0.1	0.1	0.1	0.2
Litter	155.3	195.0	12.7	186.1	232.3

Average accuracy was 16% for Japanese brome, 47% for bindweed, 50% for western wheatgrass, 63% for green needlegrass, and 66% for total aboveground biomass (Table 34).

Table 34. Percent accuracy for the four-year modelling run for the Fort Carson brome site with prescribed burning, seeding, and sugar application.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	67.20	30.52	0.454
2001	47.30	3.05	0.064
2002	11.22	0.00	0.000
2003	47.95	6.24	0.130
Bindweed			
2000	34.18	51.22	0.667
2001	9.43	73.78	0.128
2002	8.42	8.29	0.985
2003	8.64	92.70	0.093
Western wheatgrass			
2000	78.91	46.83	0.593
2001	52.53	39.74	0.757
2002	43.04	4.24	0.099
2003	123.46	70.40	0.570
Green needlegrass			
2000	25.44	26.80	0.949
2001	3.86	18.23	0.212
2002	4.19	2.22	0.530
2003	6.13	4.99	0.813
Total			
2000	246.74	174.22	0.706
2001	126.48	143.16	0.883
2002	80.51	16.70	0.207
2003	218.52	185.79	0.850

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Western wheatgrass was the dominant species at the end of 50 years in the plots that were modelled with burning, seeding, and sugar application (Table 35). Twistspine pricklypear and soapweed were major species as well. Japanese brome and bindweed had very little biomass by year 50 and no annual forbs were present.

Table 35. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding, sugar application and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	191	247	449	734	921	1094	1208
Twistspine pricklypear	4	5	5	32	83	184	249
Soapweed	0	0	5	23	78	136	230
Crested wheatgrass	0	0	5	9	10	12	12
Western wheatgrass	71	79	334	554	611	600	532
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	0	0	3	7	15	31	48
Blue grama	0	0	1	1	1	1	1
Kentucky bluegrass	0	0	1	1	1	1	0
Little bluestem	0	0	1	1	1	1	1
Sacaton	0	0	11	15	16	19	16
Sand dropseed	0	0	1	0	1	0	0
Green needlegrass	46	25	12	12	13	13	13
Ragweed	0	1	1	1	1	1	1
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	2	3	44	54	61	58	62
Bindweed	23	34	3	0	0	0	0
Scarlet beeblossum	4	4	3	1	1	0	0
Golden aster	0	0	10	15	16	19	19
Hoarhound	3	2	1	0	1	0	1
Alfalfa	0	0	1	1	1	1	0
Orange globemallow	0	0	2	0	0	0	0
Mignonette	25	23	0	0	0	0	0
Wavyleaf thistle	0	0	5	7	11	16	22
Sweetclover	0	0	0	0	0	0	0
Japanese brome	12	67	1	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	0	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	155	195	170	149	185	160	197

At the end of four years with burning, seeding, and soil inoculation simulated together, western wheatgrass was the dominant species in the plots (Table 36). In Year 4 , western wheatgrass had three times the biomass of Japanese brome. Most species decreased from Year 1 to Year 3, perhaps due to the prescribed burn in the second year and drought in the third year. By Year 4, however, total biomass was the highest of the four years.

Table 36. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding, inoculation and a four-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	159.2	215.6	123.4	84.7	217.4
Twistspine pricklypear	0.0	0.0	0.0	0.1	0.2
Soapweed	0.0	0.0	0.1	0.4	0.9
Crested wheatgrass	0.0	0.1	0.5	0.6	0.9
Western wheatgrass	60.2	73.0	56.9	45.2	134.6
Purple threeawn	0.0	0.5	0.5	0.3	0.7
Sideoats grama	0.0	0.1	0.2	0.3	0.7
Blue grama	0.0	0.1	0.8	0.6	0.6
Kentucky bluegrass	0.0	0.1	0.1	0.2	0.3
Little bluestem	0.0	0.2	0.3	0.2	0.5
Sacaton	0.0	0.2	0.3	0.5	1.5
Sand dropseed	0.0	0.3	0.4	0.4	0.8
Green needlegrass	45.7	25.8	4.0	4.3	5.9
Ragweed	0.0	0.9	1.6	2.2	3.0
Spotted knapweed	0.0	0.2	0.3	0.1	0.2
Canada thistle	0.8	1.4	2.5	3.1	8.1
Bindweed	27.5	43.5	12.9	10.2	10.2
Scarlet beeblossum	2.6	2.4	1.2	0.9	1.4
Golden aster	0.0	0.1	0.2	0.3	0.8
Hoarhound	0.0	0.1	0.2	0.2	0.4
Alfalfa	0.0	0.1	0.3	0.4	0.7
Orange globemallow	0.0	0.4	0.7	0.9	1.8
Mignonette	17.0	14.9	0.3	0.1	0.2
Wavyleaf thistle	0.0	0.1	0.2	0.3	0.7
Sweetclover	0.0	0.2	0.2	0.1	0.2
Japanese brome	5.2	49.4	37.4	12.2	40.5
Lambsquarters	0.1	0.1	0.1	0.1	0.2
Sunflower	0.0	0.2	0.2	0.1	0.3
Bladderpod	0.0	0.5	0.5	0.1	0.4
Russian thistle	0.0	0.4	0.4	0.3	0.5
Tansymustard	0.1	0.2	0.1	0.1	0.2
Litter	202.2	230.6	10.9	183.9	225.4

Average accuracy was 32% for Japanese brome and bindweed, 57% for western wheatgrass, 43% for green needlegrass, and 61% for total aboveground biomass (Table 37).

Table 37. Percent accuracy for the four-year modelling run for the Fort Carson brome site with prescribed burning, seeding, and inoculation.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	49.36	23.47	0.476
2001	37.35	13.45	0.360
2002	12.18	0.00	0.000
2003	40.53	18.41	0.454
Bindweed			
2000	43.52	18.40	0.423
2001	12.85	32.32	0.398
2002	10.21	2.63	0.258
2003	10.18	47.68	0.213
Western wheatgrass			
2000	73.04	59.79	0.819
2001	56.85	74.03	0.768
2002	45.16	1.40	0.031
2003	134.58	90.69	0.674
Green needlegrass			
2000	25.75	15.19	0.590
2001	4.02	15.47	0.260
2002	4.34	1.55	0.357
2003	5.90	3.14	0.532
Total			
2000	215.57	140.60	0.652
2001	123.37	163.29	0.756
2002	84.67	12.96	0.153
2003	217.44	194.10	0.893

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

In the 50-year EDYS simulation including burning, seeding, and soil inoculation, western wheatgrass was the dominant vegetation by Year 10 and Japanese brome and bindweed were both very low by this time (Table 38). At the end of 50 years, western wheatgrass, soapweed, and twistspine pricklypear were the dominant species. No annual forbs and very few perennial forbs were present in the plots at the end of the simulation.

Table 38. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding, inoculation and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	159	216	443	728	897	1081	1227
Twistspine pricklypear	0	0	2	8	36	134	223
Soapweed	0	0	4	22	75	136	249
Crested wheatgrass	0	0	4	8	10	12	13
Western wheatgrass	60	73	371	626	696	697	629
Purple threeawn	0	1	0	0	0	0	0
Sideoats grama	0	0	3	5	9	18	28
Blue grama	0	0	1	1	1	1	1
Kentucky bluegrass	0	0	1	1	1	1	0
Little bluestem	0	0	1	1	1	1	1
Sacaton	0	0	9	9	10	12	11
Sand dropseed	0	0	1	0	1	1	0
Green needlegrass	46	26	11	12	12	13	13
Ragweed	0	1	2	1	1	1	1
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	1	1	14	17	23	26	27
Bindweed	27	44	3	0	0	0	0
Scarlet beeblossum	3	2	1	1	1	0	0
Golden aster	0	0	7	9	10	13	12
Hoarhound	0	0	1	1	1	1	1
Alfalfa	0	0	1	1	1	0	0
Orange globemallow	0	0	2	1	0	0	0
Mignonette	17	15	0	0	0	0	0
Wavyleaf thistle	0	0	4	5	8	13	17
Sweetclover	0	0	0	0	0	0	0
Japanese brome	5	49	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	202	231	167	148	183	156	200

When burning, sugar application, and soil inoculation were simulated together, western wheatgrass and Canada thistle out-competed Japanese brome and bindweed within a four-year time period (Table 39). Most species declined in the year following the burn, with the exception of Canada thistle. Although both brome and bindweed were reduced at the end of four years, neither species were eliminated by this combination of treatments.

Table 39. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, sugar application, inoculation and a four-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	132.3	194.1	101.7	81.6	202.6
Twistspine pricklypear	0.0	0.0	0.0	0.0	0.0
Soapweed	0.0	0.1	0.1	0.1	0.2
Crested wheatgrass	0.0	0.1	0.0	0.0	0.0
Western wheatgrass	42.8	57.2	38.4	40.8	124.8
Purple threeawn	0.0	0.6	0.1	0.2	0.2
Sideoats grama	0.0	0.1	0.0	0.1	0.1
Blue grama	0.0	0.2	0.0	0.0	0.1
Kentucky bluegrass	0.0	0.1	0.0	0.0	0.1
Little bluestem	0.0	0.2	0.0	0.0	0.1
Sacaton	0.0	0.2	0.1	0.1	0.3
Sand dropseed	0.0	0.3	0.0	0.0	0.1
Green needlegrass	30.4	17.4	2.8	3.4	4.5
Ragweed	0.0	1.1	0.5	0.8	1.1
Spotted knapweed	0.0	0.2	0.0	0.0	0.0
Canada thistle	7.8	11.9	14.1	8.8	32.9
Bindweed	24.1	39.2	10.7	8.8	8.1
Scarlet beeblossum	1.3	1.3	0.5	0.6	0.7
Golden aster	0.0	0.1	0.0	0.1	0.2
Hoarhound	5.1	5.0	0.7	0.7	0.7
Alfalfa	0.0	0.1	0.0	0.1	0.4
Orange globemallow	0.1	0.6	0.2	0.3	0.8
Mignonette	16.5	18.9	0.1	0.0	0.0
Wavyleaf thistle	0.0	0.1	0.0	0.1	0.2
Sweetclover	0.0	0.2	0.0	0.0	0.0
Japanese brome	3.6	37.1	33.1	16.6	27.1
Lambsquarters	0.1	0.2	0.0	0.0	0.0
Sunflower	0.0	0.2	0.0	0.0	0.0
Bladderpod	0.2	0.9	0.0	0.0	0.0
Russian thistle	0.0	0.5	0.0	0.0	0.0
Tansymustard	0.2	0.2	0.0	0.0	0.0
Litter	139.5	172.3	11.4	154.6	199.7

When prescribed burning, sugar application, and inoculation were included together in the model, average accuracy was 36% for Japanese brome, 47% for bindweed, 53% for western wheatgrass, 57% for green needlegrass, and 59% for total aboveground biomass (Table 40). The third year, when the drought occurred, once again had very poor accuracy for most species.

Table 40. Percent accuracy for the four-year modelling run for the Fort Carson brome site with prescribed burning, sugar application, and inoculation.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	37.07	31.57	0.852
2001	33.09	10.96	0.331
2002	16.63	0.01	0.001
2003	27.12	6.97	0.257
Bindweed			
2000	39.18	35.94	0.917
2001	10.71	63.11	0.170
2002	8.82	6.06	0.687
2003	8.07	75.56	0.107
Western wheatgrass			
2000	57.18	40.16	0.702
2001	38.44	41.79	0.920
2002	40.76	1.68	0.041
2003	124.80	58.92	0.472
Green needlegrass			
2000	17.35	9.64	0.556
2001	2.81	14.30	0.197
2002	3.38	2.23	0.661
2003	4.52	3.97	0.879
Total			
2000	194.09	142.11	0.732
2001	101.74	150.16	0.678
2002	81.62	10.77	0.132
2003	202.58	167.60	0.827

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

By Year 10 of the 50-year simulation that included burning, sugar application, and soil inoculation, western wheatgrass was the dominate species and Japanese brome was eliminated (Table 41). Soapweed, Canada thistle, and sideoats grama were also important species by Year 50, although western wheatgrass was the most prevalent species.

Table 41. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, sugar application, inoculation and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	132	194	454	709	804	875	923
Twistspine pricklypear	0	0	0	0	2	7	23
Soapweed	0	0	1	3	14	53	104
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	43	57	361	585	650	628	607
Purple threeawn	0	1	0	0	0	0	0
Sideoats grama	0	0	0	1	13	41	53
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	0	0	1	1	0
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	1	1	2	3	3
Sand dropseed	0	0	0	0	0	0	0
Green needlegrass	30	17	6	7	8	9	9
Ragweed	0	1	1	1	1	1	0
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	8	12	77	106	97	96	84
Bindweed	24	39	2	0	0	0	0
Scarlet beeblossum	1	1	1	0	0	0	0
Golden aster	0	0	1	4	13	29	27
Hoarhound	5	5	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	0	1	1	0	0	0	0
Mignonette	17	19	0	0	0	0	0
Wavyleaf thistle	0	0	0	0	3	8	10
Sweetclover	0	0	0	0	0	0	0
Japanese brome	4	37	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	140	172	172	153	183	158	194

In the EDYS simulation that included all four treatments (burning, seeding, sugar application, and soil inoculation), Japanese brome biomass doubled in the year following the burn and then decreased in the third year due to drought (Table 42). Western wheatgrass was the dominant species in every year and biomass of most other species was very low. The biennial forb wavyleaf thistle emerged as a major species in this treatment combination.

Table 42. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding, sugar application, inoculation and a four-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	140.2	200.1	173.3	90.2	180.4
Twistspine pricklypear	0.0	0.0	0.0	0.0	0.0
Soapweed	0.0	0.1	0.2	0.3	0.4
Crested wheatgrass	0.0	0.1	0.3	0.5	1.1
Western wheatgrass	52.9	60.7	50.5	34.7	101.1
Purple threeawn	0.0	0.6	0.2	0.1	0.2
Sideoats grama	0.0	0.1	0.1	0.1	0.3
Blue grama	0.0	0.1	0.6	0.8	0.9
Kentucky bluegrass	1.3	1.4	0.7	0.3	1.0
Little bluestem	0.0	0.2	0.0	0.1	0.1
Sacaton	0.0	0.2	0.2	0.6	2.0
Sand dropseed	0.0	0.3	0.2	0.2	0.4
Green needlegrass	30.4	17.3	2.7	3.6	5.3
Ragweed	0.0	0.9	0.9	1.0	1.1
Spotted knapweed	0.0	0.2	0.0	0.0	0.0
Canada thistle	0.0	0.1	0.0	0.1	0.2
Bindweed	30.2	47.7	13.0	10.2	10.2
Scarlet beeblossum	1.2	1.2	0.3	0.2	0.5
Golden aster	0.1	0.2	0.1	0.1	0.4
Hoarhound	1.3	1.3	0.2	0.2	0.2
Alfalfa	0.0	0.1	0.2	0.3	0.8
Orange globemallow	0.1	0.6	0.2	0.2	0.6
Mignonette	10.7	11.3	0.3	0.0	0.0
Wavyleaf thistle	6.7	10.2	14.9	8.4	26.2
Sweetclover	0.1	0.3	0.0	0.0	0.0
Japanese brome	4.8	43.0	87.5	28.1	27.3
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.0	0.2	0.0	0.0	0.0
Bladderpod	0.0	0.6	0.0	0.0	0.0
Russian thistle	0.0	0.4	0.0	0.0	0.0
Tansymustard	0.5	0.3	0.0	0.0	0.0
Litter	157.7	177.5	23.2	220.8	263.4

Average accuracy was 30% for Japanese brome, 33% for bindweed, 42% for western wheatgrass, 67% for green needlegrass, and 62% for total aboveground biomass (Table 43).

Table 43. Percent accuracy for the four-year modelling run for the Fort Carson brome site with prescribed burning, seeding, sugar application, and inoculation.

Variable	Predicted	Sampled	Accuracy
Japanese Brome			
2000	43.02	38.23	0.889
2001	87.47	16.60	0.190
2002	28.14	0.13	0.005
2003	27.31	3.15	0.115
Bindweed			
2000	47.72	29.14	0.611
2001	13.00	45.72	0.284
2002	10.24	2.69	0.263
2003	10.21	63.89	0.160
Western wheatgrass			
2000	60.74	34.76	0.572
2001	50.50	23.98	0.475
2002	34.66	3.50	0.101
2003	101.12	55.28	0.547
Green needlegrass			
2000	17.31	16.83	0.972
2001	2.69	9.08	0.296
2002	3.64	1.63	0.448
2003	5.29	5.17	0.978
Total			
2000	200.08	133.85	0.669
2001	173.35	137.89	0.795
2002	90.24	8.95	0.099
2003	180.41	162.94	0.903

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

By Year 10, western wheatgrass was the dominant species in the plots and it continued to dominant throughout the 50-year simulation (Table 44). Japanese brome growth was very low by Year 10, as was growth of bindweed. No annual forbs and very few perennial forbs were present in the plots at the end of the simulation. Wavyleaf thistle biomass stayed relatively high towards the end of the run.

Table 44. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome site, with prescribed burning, seeding, sugar application, inoculation and a four-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	140	200	452	718	840	939	974
Twistspine pricklypear	0	0	0	1	2	8	33
Soapweed	0	0	2	10	42	107	123
Crested wheatgrass	0	0	10	13	15	16	18
Western wheatgrass	53	61	329	574	643	652	631
Purple threeawn	0	1	0	0	0	0	0
Sideoats grama	0	0	3	4	15	38	56
Blue grama	0	0	1	0	0	0	0
Kentucky bluegrass	1	1	2	2	3	2	1
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	21	21	16	12	6
Sand dropseed	0	0	1	0	0	0	0
Green needlegrass	30	17	11	12	12	13	13
Ragweed	0	1	1	1	1	1	1
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	0	0	2	2	2	2	3
Bindweed	30	48	3	0	0	0	0
Scarlet beeblossum	1	1	0	0	0	0	0
Golden aster	0	0	6	6	6	5	4
Hoarhound	1	1	0	0	0	0	0
Alfalfa	0	0	4	2	2	1	1
Orange globemallow	0	1	2	0	0	0	0
Mignonette	11	11	0	0	0	0	0
Wavyleaf thistle	7	10	53	69	80	81	84
Sweetclover	0	0	0	0	0	0	0
Japanese brome	5	43	1	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	158	178	170	152	186	167	197

6.1.5 Herbivory

With light herbivory (3 insects/m^2 and 0.30 rabbits/m^2), total biomass at Year 50 was 15% lower than with no herbivory (Table 45). No changes were seen in the succulents because they are not a preferred species of the herbivores (Appendix Table 25). Biomass of western wheatgrass was 96% lower in plots with herbivory than in those without herbivory. Herbivores also negatively affected growth of crested wheatgrass, and sideoats grama. Growth of Japanese brome and bindweed were not affected by the herbivory. Wavyleaf thistle and golden aster increased because preference for this species was not very high and competition from perennial grasses was reduced.

Table 45. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with light herbivory from insects (3 per m^2) and rabbits (0.30 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	57	460	740	876	1012	1034
Twistspine pricklypear	0	0	3	14	55	194	249
Soapweed	0	0	20	137	251	250	249
Crested wheatgrass	0	0	1	1	1	1	1
Western wheatgrass	0	0	4	8	11	18	20
Purple threeawn	0	0	1	0	0	0	0
Sideoats grama	0	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	9	6	3	2	1
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	175	206	131	49	18
Sand dropseed	0	0	0	0	0	0	0
Green needlegrass	0	0	1	1	1	1	1
Ragweed	0	0	6	5	4	3	2
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	0	0	29	28	24	18	15
Bindweed	12	14	0	0	0	0	0
Scarlet beeblossum	1	1	6	4	2	1	1
Golden aster	0	0	98	141	136	134	107
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	0	0	1	0	0	0	0
Mignonette	2	1	0	0	0	0	0
Wavyleaf thistle	0	0	106	190	255	341	370
Sweetclover	1	1	0	0	0	0	0
Japanese brome	2	36	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0
Litter	99	103	180	152	213	182	217

Results of the simulation with moderate herbivory were very similar to those with light herbivory (Table 46). It appears that doubling the density of herbivores does not cause a linear increase in changes to biomass and species composition.

Table 46. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with moderate herbivory from insects (6 per m^2) and rabbits (0.56 per hectare) (mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	29	454	709	857	933	1035
Twistspine pricklypear	0	0	1	4	20	87	242
Soapweed	0	0	18	98	244	250	249
Crested wheatgrass	0	0	1	1	1	1	1
Western wheatgrass	0	0	4	8	11	18	19
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	0	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	9	6	3	2	1
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	148	167	108	39	14
Sand dropseed	0	0	0	0	0	0	0
Green needlegrass	0	0	1	1	1	1	1
Ragweed	0	0	3	4	3	3	2
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	0	0	31	29	24	20	15
Bindweed	12	11	0	0	0	0	0
Scarlet beeblossum	1	1	6	4	3	1	1
Golden aster	0	0	133	202	191	182	142
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	0	0	0	0	0	0	0
Mignonette	2	1	0	0	0	0	0
Wavyleaf thistle	0	0	100	185	248	329	349
Sweetclover	1	1	0	0	0	0	0
Japanese brome	2	13	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0
Litter	99	103	174	150	203	182	215

When impacts of heavy herbivory were simulated, total biomass was 27% lower than without herbivory (Table 47). Twistspine pricklypear biomass decreased slightly, but soapweed was significantly lower. As with light and moderate herbivory, biomass of perennial grasses was very low throughout the simulation, most likely because rabbits prefer these species over most others on the plots. Golden aster and wavyleaf thistle biomass increased greatly and these were the dominant species at the end of the simulation.

Table 47. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with heavy herbivory from insects (12 per m^2) and rabbits (0.78 per hectare)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	15	402	632	724	788	884
Twistspine pricklypear	0	0	0	2	9	45	185
Soapweed	0	0	4	4	4	5	4
Crested wheatgrass	0	0	1	1	1	1	1
Western wheatgrass	0	0	4	11	16	25	28
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	0	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	3	2	1	1	1
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	25	32	13	5	2
Sand dropseed	0	0	0	0	0	0	0
Green needlegrass	0	0	1	1	1	1	1
Ragweed	0	0	3	4	4	4	3
Spotted knapweed	0	0	0	0	0	0	0
Canada thistle	0	0	35	34	30	23	19
Bindweed	12	7	0	0	0	0	0
Scarlet beeblossum	1	1	6	4	3	2	1
Golden aster	0	0	213	342	373	354	289
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	0	0	0	0	0	0	0
Mignonette	2	1	0	0	0	0	0
Wavyleaf thistle	0	0	106	194	268	322	349
Sweetclover	1	0	0	0	0	0	0
Japanese brome	2	5	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0
Litter	99	103	161	154	198	165	201

6.1.6 Cattle Grazing

With light grazing (64 Ac/AU), total biomass was 8% higher than without grazing but no change was seen in pricklypear and soapweed biomass (Table 48). Growth of western wheatgrass was slightly higher than without grazing and that of crested wheatgrass and sideoats grama was slightly lower. No other differences were observed.

Table 48. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with light grazing (64 acres per animal unit)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	86	400	723	982	1185	1224
Twistspine pricklypear	0	0	5	26	102	249	249
Soapweed	0	0	21	118	252	250	250
Crested wheatgrass	0	0	9	20	24	28	31
Western wheatgrass	0	0	106	343	420	502	559
Purple threeawn	0	0	2	1	1	0	0
Sideoats grama	0	0	14	21	22	27	28
Blue grama	0	0	1	1	0	0	0
Kentucky bluegrass	0	0	5	3	2	1	1
Little bluestem	0	0	6	4	3	2	2
Sacaton	0	0	66	75	51	29	11
Sand dropseed	0	0	3	1	1	0	0
Green needlegrass	0	0	2	3	3	3	3
Ragweed	0	0	8	4	3	2	1
Spotted knapweed	0	0	1	0	0	0	0
Canada thistle	0	0	9	7	7	6	6
Bindweed	12	23	9	1	0	0	0
Scarlet beeblossum	1	1	5	3	2	1	1
Golden aster	0	0	35	46	38	31	24
Hoarhound	0	1	2	1	1	1	1
Alfalfa	0	0	3	2	2	1	1
Orange globemallow	0	1	20	3	1	0	0
Mignonette	2	2	0	0	0	0	0
Wavyleaf thistle	0	0	31	40	47	49	55
Sweetclover	1	2	0	0	0	0	0
Japanese brome	2	53	38	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0
Litter	99	103	174	148	204	183	216

When moderate grazing (32 Ac/AU) was included in the model, total aboveground biomass at Year 50 was 13% lower than without grazing (Table 49). Long-term species composition was affected by grazing. Biomass of twistspine pricklypear went from 250 g/m^2 in Year 50 in ungrazed plots to 0 g/m^2 in grazed plots, apparently in response to increased competition form other species. Biomass of western wheatgrass increased 38% over ungrazed plots and it was the dominant species at the end of the simulation.

Table 49. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with moderate grazing (32 acres per animal unit)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	78	382	735	926	1001	1053
Twistspine pricklypear	0	0	0	0	0	0	0
Soapweed	0	0	27	146	252	250	250
Crested wheatgrass	0	0	11	18	21	22	24
Western wheatgrass	0	0	193	455	550	641	701
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	0	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	0	0	0	0	0
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	0	0	0	0	0
Sand dropseed	0	0	0	0	0	0	0
Green needlegrass	0	0	2	2	3	3	3
Ragweed	0	0	3	1	1	0	0
Spotted knapweed	0	0	1	0	0	0	0
Canada thistle	0	0	10	7	6	5	4
Bindweed	12	23	11	1	0	0	0
Scarlet beeblossum	1	1	5	3	2	1	1
Golden aster	0	0	64	67	54	41	32
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	0	0	1	0	0	0	0
Mignonette	2	1	0	0	0	0	0
Wavyleaf thistle	0	0	35	34	38	36	38
Sweetclover	1	0	0	0	0	0	0
Japanese brome	2	49	18	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0
Litter	99	102	161	140	199	172	209

When impact of heavy grazing (21 Ac/AU) was included in the model, impacts were not much different that with moderate grazing (Table 50). Total aboveground biomass at Year 50 was 14% lower than without grazing. Western wheatgrass biomass increased 27% and was the dominant species at the end of the simulation.

Table 50. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with heavy grazing (21 acres per animal unit)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	80	383	737	924	994	1046
Twistspine pricklypear	0	0	0	0	0	0	0
Soapweed	0	0	28	153	252	250	250
Crested wheatgrass	0	0	10	17	20	21	22
Western wheatgrass	0	0	183	452	551	637	697
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	0	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	0	0	0	0	0
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	0	0	0	0	0
Sand dropseed	0	0	0	0	0	0	0
Green needlegrass	0	0	2	2	3	3	3
Ragweed	0	0	4	2	1	1	0
Spotted knapweed	0	0	1	0	0	0	0
Canada thistle	0	0	11	8	7	6	5
Bindweed	12	23	11	1	0	0	0
Scarlet beeblossum	1	1	5	3	2	1	1
Golden aster	0	0	57	61	49	38	29
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	0	0	4	0	0	0	0
Mignonette	2	1	0	0	0	0	0
Wavyleaf thistle	0	0	36	36	39	37	38
Sweetclover	1	1	0	0	0	0	0
Japanese brome	2	52	29	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0
Litter	99	102	163	140	200	171	210

6.1.7 Military Training

When impact of an M-1 Abrams tank making one pass through the plots in Year 5 was included in the model, there were no long-term changes in total aboveground biomass when compared to the undisturbed plots (Table 51). There were also no changes in vegetation at Year 50 when compared to undisturbed plots, although biomass of wavyleaf thistle was slightly higher and biomass of golden aster and sideoats grama was slightly lower than in undisturbed plots. In Year 5, when the impact occurred, total aboveground biomass decreased but by Year 10 total aboveground biomass was only 8% lower than in undisturbed plots at Year 10.

Table 51. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with military training (M-1 Abrams tank training in Year 5)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	86	62	364	693	975	1168	1214
Twistspine pricklypear	0	0	1	5	29	113	249	249
Soapweed	0	0	1	15	98	252	250	250
Crested wheatgrass	0	0	1	7	19	24	30	33
Western wheatgrass	0	0	3	68	286	362	448	513
Purple threeawn	0	0	1	2	1	1	0	0
Sideoats grama	0	0	2	16	26	26	31	31
Blue grama	0	0	0	1	1	0	0	0
Kentucky bluegrass	0	0	1	5	4	2	1	1
Little bluestem	0	0	1	6	4	3	2	2
Sacaton	0	0	5	76	109	77	44	17
Sand dropseed	0	0	1	2	1	0	0	0
Green needlegrass	0	0	0	2	3	3	3	3
Ragweed	0	0	2	11	7	5	4	3
Spotted knapweed	0	0	2	2	0	0	0	0
Canada thistle	0	0	2	11	11	11	10	9
Bindweed	12	23	20	9	1	0	0	0
Scarlet beeblossum	1	1	1	3	2	1	1	1
Golden aster	0	0	1	18	30	28	25	21
Hoarhound	0	1	0	1	1	1	1	1
Alfalfa	0	0	1	3	2	1	1	1
Orange globemallow	0	1	5	23	4	1	0	0
Mignonette	2	2	0	0	0	0	0	0
Wavyleaf thistle	0	0	3	35	54	61	67	77
Sweetclover	1	2	0	0	0	0	0	0
Japanese brome	2	53	8	43	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0	0
Litter	99	103	451	177	148	204	185	218

When impacts of an M-1 Abrams tank making one pass through the plots every five years were included in the model, total aboveground biomass at Year 50 was 67% lower than in undisturbed plots (Table 52). Species composition was also affected. At Year 50, biomass of twistspine pricklypear was 13%, soapweed was 96% lower, and western wheatgrass was 77% lower than in undisturbed plots. No species increased and most other grasses and forbs had disappeared by the end of the simulation.

Table 52. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with military training (M-1 Abrams tank training every 5 years)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	86	62	130	172	270	380	401
Twistspine pricklypear	0	0	1	5	25	93	214	216
Soapweed	0	0	1	3	4	6	8	11
Crested wheatgrass	0	0	1	3	2	1	0	0
Western wheatgrass	0	0	3	22	85	118	113	118
Purple threeawn	0	0	1	1	0	0	0	0
Sideoats grama	0	0	2	9	13	13	11	11
Blue grama	0	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	1	3	2	1	1	0
Little bluestem	0	0	1	2	1	0	0	0
Sacaton	0	0	5	30	5	1	1	0
Sand dropseed	0	0	1	1	0	0	0	0
Green needlegrass	0	0	0	1	1	0	0	0
Ragweed	0	0	2	2	2	3	2	2
Spotted knapweed	0	0	2	1	0	0	0	0
Canada thistle	0	0	2	6	9	9	7	8
Bindweed	12	23	20	7	0	0	0	0
Scarlet beeblossum	1	1	1	1	0	0	0	0
Golden aster	0	0	1	2	2	1	0	0
Hoarhound	0	1	0	0	0	0	0	0
Alfalfa	0	0	1	1	0	0	0	0
Orange globemallow	0	1	5	6	1	0	0	0
Mignonette	2	2	0	0	0	0	0	0
Wavyleaf thistle	0	0	3	12	18	22	22	32
Sweetclover	1	2	0	0	0	0	0	0
Japanese brome	2	53	8	14	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0	0
Litter	99	103	451	321	336	354	376	388

When impacts of a HMMWV passing through the plots every five years was included in the model, the impacts were the same as with the M-1 Abrams tank. Although these two vehicles have different "footprints", the cumulative impact was the same (Table 53).

Table 53. EDYS simulation of vegetation dynamics at the Fort Carson Landscape brome control site with military training (HMMWV training every 5 years)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	20	86	62	130	172	270	380	401
Twistspine pricklypear	0	0	1	5	25	93	214	216
Soapweed	0	0	1	3	4	6	8	11
Crested wheatgrass	0	0	1	3	2	1	0	0
Western wheatgrass	0	0	3	22	85	118	113	118
Purple threeawn	0	0	1	1	0	0	0	0
Sideoats grama	0	0	2	9	13	13	11	11
Blue grama	0	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	1	3	2	1	1	0
Little bluestem	0	0	1	2	1	0	0	0
Sacaton	0	0	5	30	5	1	1	0
Sand dropseed	0	0	1	1	0	0	0	0
Green needlegrass	0	0	0	1	1	0	0	0
Ragweed	0	0	2	2	2	3	2	2
Spotted knapweed	0	0	2	1	0	0	0	0
Canada thistle	0	0	2	6	9	9	7	8
Bindweed	12	23	20	7	0	0	0	0
Scarlet beeblossum	1	1	1	1	0	0	0	0
Golden aster	0	0	1	2	2	1	0	0
Hoarhound	0	1	0	0	0	0	0	0
Alfalfa	0	0	1	1	0	0	0	0
Orange globemallow	0	1	5	6	1	0	0	0
Mignonette	2	2	0	0	0	0	0	0
Wavyleaf thistle	0	0	3	12	18	22	22	32
Sweetclover	1	2	0	0	0	0	0	0
Japanese brome	2	53	8	14	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0	0
Tansymustard	1	0	0	0	0	0	0	0
Litter	99	103	451	321	336	354	376	388

6.1.5 Brome Modelling Summary

In all the treatments, including the control, the Japanese brome community declined over the four years of the study. The decline was most notable in 2002. EDYS in some treatments simulated this decline, but not to the extent that it occurred in the field. In the undisturbed, burned, and burned and seeded plots, Japanese brome was the dominant species after four years (Table 54). When sugar application was incorporated as a treatment, western wheatgrass became the dominant species. Application of sugar causes an increase in growth of heterotrophic soil microorganisms that uptake nitrogen and causes a soil nitrogen limitation. This nitrogen limitation favors late-successional species such as perennial grasses over early-successional species such as Japanese brome. The same results were seen with soil inoculation. Inoculation with native soil should favor late-successional species if mycorrhizal fungi increase and enhance ability of perennial plants to uptake nutrients. After 50 years, western wheatgrass was the dominant species, regardless of the treatment imposed during the first four years. In the treatments that included inoculation, western wheatgrass had consistently higher biomass than in treatments without inoculation. Late-successional, drought-tolerant soapweed and twistspine pricklypear were also favored at the end of 50 years.

Table 54. Dominant vegetation species in the Fort Carson brome EDYS simulations after 4 and 50 years.

Treatment	Dominant Species	
	4 years	50 years
Control – Undisturbed	Japanese brome	Western wheatgrass Soapweed Twistspine pricklypear
Burned	Japanese brome Western wheatgrass	Western wheatgrass Soapweed Twistspine pricklypear
Burned, seeded	Japanese brome Western wheatgrass	Western wheatgrass Soapweed Twistspine pricklypear
Burned, sugar application	Western wheatgrass Japanese brome	Western wheatgrass Twistspine pricklypear Soapweed
Burned, seeded, sugar application	Western wheatgrass	Western wheatgrass Twistspine pricklypear Soapweed
Burned, seeded, inoculation	Western wheatgrass	Western wheatgrass Soapweed Twistspine pricklypear
Burned, sugar application, inoculation	Western wheatgrass	Western wheatgrass Soapweed
Burned, seeded, sugar application, inoculation	Western wheatgrass	Western wheatgrass Soapweed

Light levels of herbivory caused a decrease in perennial grasses and an increase in golden aster and wavyleaf thistle. The major species at the end of 50 years were wavyleaf thistle, twistspine pricklypear, soapweed, and golden aster whereas the same community without herbivory was dominated by western wheatgrass and the two succulents. Moderate herbivory produced the same results as light herbivory, perhaps because the increase in density was not enough to significantly affect the plants. Heavy herbivory caused a 27% decrease in total aboveground biomass and significantly reduced the biomass of soapweed and perennial grasses. At the end of 50 years, the community was dominated by wavyleaf thistle and golden aster.

When light grazing was included in the model, no substantial impacts were seen in total aboveground biomass or species composition at the end of 50 years. When moderate and heavy grazing were included, total aboveground biomass was about 14% lower than in ungrazed plots and long-term species composition was affected. Biomass of twistspine pricklypear disappeared, even though it was a major species in ungrazed plots. Biomass of western wheatgrass increased was the dominant species after 50 years.

When impact of an M-1 Abrams tank making one pass through the plots in Year 5 was included in the model, there were no long-term changes in total aboveground biomass or species composition when compared to the undisturbed plots. When impacts of an M-1 Abrams tank or a HMMWV making one pass through the plots every five years were included in the model, total aboveground biomass at Year 50 was 67% lower than in undisturbed plots. Species composition was also affected. At Year 50, biomass of twistspine pricklypear was 13%, soapweed was 96% lower, and western wheatgrass was 77% lower than in undisturbed plots. No species increased and most other grasses and forbs had disappeared by the end of the simulation.

6.2 Knapweed Community

6.2.1 Community-Wide Accuracy

EDYS was parameterized for the knapweed community, for each of the different plot-level treatments. The initial conditions were those typical of present conditions. The simulation runs were for four and fifty years. The results of the EDYS simulations for the four years at the knapweed site plots (mean of forty plots) are shown in Table 55. Simulation values were compared to field-collected aboveground biomass data for all 40 plots for each of the four years (Table 56). Accuracy was high for knapweed and total aboveground biomass, with the exception of the third year.

Table 55. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site (mean of forty plots) and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	74.9	66.5	104.9	108.1	182.6
Twistspine pricklypear	2.0	2.2	2.8	3.5	4.3
Soapweed	2.1	2.4	4.1	5.9	8.2
Crested wheatgrass	0.0	0.1	0.5	0.9	1.4
Western wheatgrass	1.9	2.6	10.4	19.3	56.4
Purple threeawn	4.6	2.0	2.9	3.2	3.6
Sideoats grama	4.7	2.4	7.1	16.7	30.4
Blue grama	0.8	0.7	1.5	2.4	2.7
Kentucky bluegrass	0.9	1.1	2.9	3.5	6.3
Little bluestem	0.7	0.7	2.0	4.0	7.1
Sacaton	0.0	0.2	1.8	5.2	11.2
Sand dropseed	0.7	0.9	1.9	2.7	3.9
Green needlegrass	4.0	2.3	2.8	2.9	3.2
Ragweed	0.3	1.4	6.8	6.3	5.4
Spotted knapweed	38.9	27.7	44.7	13.6	4.1
Canada thistle	0.0	0.2	0.6	1.7	3.1
Bindweed	0.0	0.2	0.4	0.3	0.2
Scarlet beeblossum	0.5	0.6	0.9	0.9	1.0
Golden aster	0.0	0.1	0.7	2.4	5.3
Hoarhound	0.0	0.2	0.2	0.1	0.1
Alfalfa	0.0	0.1	0.6	2.0	7.1
Orange globemallow	0.2	1.1	2.7	4.6	7.6
Mignonette	0.0	0.3	0.6	0.1	0.0
Wavyleaf thistle	0.0	0.2	0.7	1.8	3.4
Sweetclover	12.3	14.8	3.0	0.6	0.1
Japanese brome	0.0	0.2	1.7	3.4	6.4
Lambsquarters	0.0	0.2	0.0	0.0	0.0
Sunflower	0.2	0.3	0.1	0.0	0.0
Bladderpod	0.1	0.8	0.1	0.0	0.0
Russian thistle	0.0	0.6	0.4	0.2	0.1
Tansymustard	0.0	0.1	0.0	0.0	0.0
Litter	86.7	133.6	294.9	328.9	281.5

Table 56. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	27.65	34.46	0.802
2001	44.74	53.43	0.837
2002	13.55	0.33	0.024
2003	4.10	4.83	0.850
Blue grama			
2000	2.41	4.21	0.574
2001	7.14	10.89	0.655
2002	16.69	2.54	0.152
2003	30.38	18.99	0.625
Western wheatgrass			
2000	2.55	3.75	0.681
2001	10.36	9.65	0.932
2002	19.34	0.80	0.041
2003	56.37	32.79	0.582
Total biomass			
2000	66.46	95.89	0.693
2001	104.89	124.12	0.845
2002	108.10	11.79	0.109
2003	182.60	160.37	0.878

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

In 2000, the dominant species was spotted knapweed. However, the production of this species declined drastically in 2002 and 2003. Other species such as western wheatgrass and blue grama became dominant as spotted knapweed decreased. These trends were well simulated by the EDYS model. The year 2002, however, resulted in very low total biomass which was not adequately simulated by the EDYS model. One possibility is that the actual precipitation in the study plots was lower than that used in the simulation.

The 95% confidence intervals of the population means of each of the composite variables were calculated for the 2000 to 2004 sampled values. These intervals give the statistical ranges for the means of each variable that are the best statistical estimates of the true value of that mean. As such, they are a measurement of the sample accuracy for that variable. These values were then compared to the 95% confidence intervals of the EDYS predicted values for the variables.

In 8 of the 12 comparisons, 95% confidence intervals of the actual and EDYS results overlapped for both species (Figure 7), indicating that the EDYS simulation was, in most cases, at least as accurate as the sampling technique for these variables.

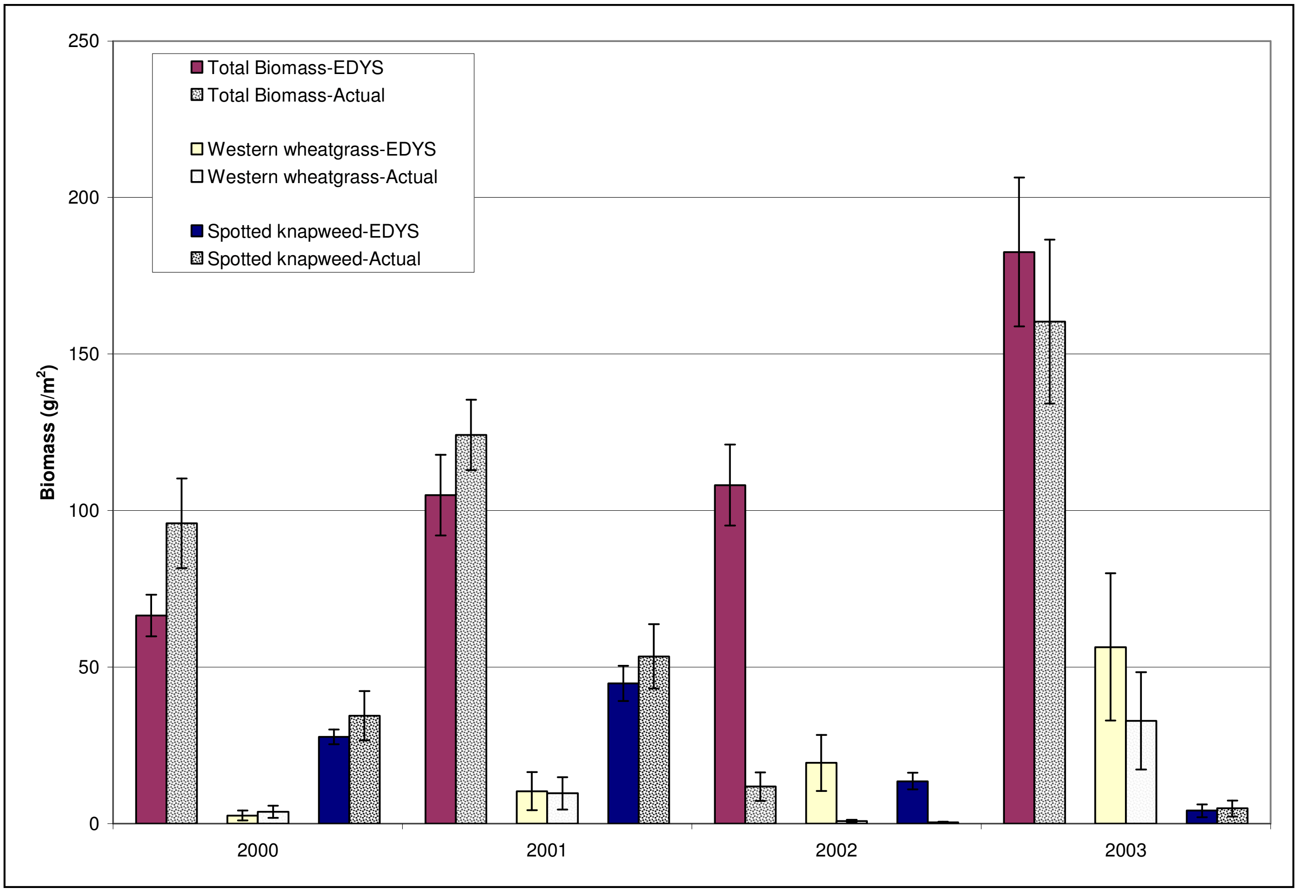

Figure 7. Comparison of aboveground biomass values (g/m^2) between actual and EDYS simulation results for the Fort Carson knapweed site.

6.2.2 Baseline Conditions

In the four-year EDYS run with no disturbance, spotted knapweed increased in the second year and decreased in the third and fourth years (Table 57). The decrease in the third year may have been due to the low amount of rainfall that year. At the end of the four years, western wheatgrass was the dominant species on the plots. Biomass of spotted knapweed was still relatively high, however, and because it is a prolific seed producer it could once again out compete the other species.

Table 57. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, under baseline conditions (i.e., no burning, no seeding, no sugar application, and no inoculation) and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	89.4	78.5	199.6	130.8	198.4
Twistspine pricklypear	2.0	2.2	2.9	3.4	4.2
Soapweed	4.7	5.2	7.4	8.2	10.4
Crested wheatgrass	0.0	0.1	0.2	0.2	0.3
Western wheatgrass	5.2	7.1	30.1	27.1	85.2
Purple threeawn	0.0	0.7	1.2	0.8	0.9
Sideoats grama	1.1	0.7	2.0	1.7	3.1
Blue grama	0.0	0.2	0.2	0.1	0.2
Kentucky bluegrass	6.2	6.7	17.0	15.8	28.9
Little bluestem	0.0	0.3	0.6	0.4	0.7
Sacaton	0.0	0.2	1.4	0.9	1.6
Sand dropseed	1.7	1.6	3.0	2.2	3.6
Green needlegrass	30.4	17.4	20.9	21.0	22.8
Ragweed	0.0	1.2	6.7	4.2	3.5
Spotted knapweed	33.1	24.0	86.7	28.0	19.6
Canada thistle	0.0	0.1	0.4	0.3	0.5
Bindweed	0.0	0.2	0.4	0.2	0.2
Scarlet beeblossum	0.3	0.4	0.6	0.5	0.5
Golden aster	0.0	0.1	0.7	0.5	1.5
Hoarhound	0.0	0.2	0.2	0.1	0.1
Alfalfa	0.0	0.1	0.3	0.1	0.2
Orange globemallow	0.5	1.6	4.3	2.6	3.1
Mignonette	0.0	0.3	0.4	0.0	0.0
Wavyleaf thistle	0.0	0.1	0.4	0.3	0.6
Sweetclover	4.0	5.0	1.1	0.0	0.0
Japanese brome	0.1	0.9	9.8	11.9	6.8
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.0	0.2	0.1	0.0	0.0
Bladderpod	0.0	0.8	0.1	0.0	0.0
Russian thistle	0.0	0.6	0.6	0.1	0.0
Tansymustard	0.0	0.1	0.0	0.0	0.0
Litter	102.9	153.6	277.6	326.6	314.0

Average accuracy was 52% for spotted knapweed, 67% for blue grama, 66% for western wheatgrass, and 59% for total aboveground biomass (Table 58). As with the brome site, accuracy was low in the third year for most species. This low accuracy may have occurred because on-site precipitation data were not available.

Table 58. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	23.98	56.31	0.426
2001	86.74	86.35	0.995
2002	28.00	0.16	0.006
2003	19.59	12.52	0.639
Blue grama			
2000	0.65	0.86	0.760
2001	2.03	2.30	0.884
2002	1.72	2.19	0.787
2003	3.12	11.83	0.264
Western wheatgrass			
2000	7.07	7.86	0.900
2001	30.06	21.07	0.701
2002	27.12	1.42	0.052
2003	85.18	86.23	0.988
Total biomass			
2000	78.49	102.51	0.766
2001	199.63	164.04	0.822
2002	130.78	7.99	0.061
2003	198.42	275.70	0.720

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Although at Year 4 there was still substantial knapweed present in the plots. Under baseline conditions, spotted knapweed declined to almost zero by Year 10 (Table 59). At this time (Year 10), western wheatgrass was the dominant species, followed by Kentucky bluegrass. By the end of the 50-year simulation, western wheatgrass, soapweed, and twistspine pricklypear were the dominant species. Western wheatgrass, soapweed, and twistspine pricklypear all have a high drought tolerance and are late-successional species and, therefore, could be expected to dominate in an undisturbed community.

Table 59. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, under baseline conditions (i.e., no burning, no seeding, no sugar application, and no inoculation) and a 50-year simulation run.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	78	433	757	962	1045	1113
Twistspine pricklypear	2	2	15	68	103	110	130
Soapweed	5	5	34	166	252	251	251
Crested wheatgrass	0	0	1	1	1	1	1
Western wheatgrass	5	7	258	407	503	584	634
Purple threeawn	0	1	1	0	0	0	0
Sideoats grama	1	1	7	9	12	24	36
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	6	7	74	68	56	40	28
Little bluestem	0	0	1	0	0	0	0
Sacaton	0	0	2	1	1	1	0
Sand dropseed	2	2	4	2	1	1	1
Green needlegrass	30	17	29	29	29	29	30
Ragweed	0	1	2	1	1	0	0
Spotted knapweed	33	24	0	0	0	0	0
Canada thistle	0	0	1	0	0	0	0
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	0	0	0	0	0
Golden aster	0	0	2	2	1	2	1
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	1	2	1	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	1	1	1	1	1
Sweetclover	4	5	0	0	0	0	0
Japanese brome	0	1	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	103	154	161	137	196	174	206

6.2.3 Biological Control

Spotted knapweed increased in Year 2 and then steadily declined in Years 3 and 4 in the EDYS simulation with knapweed-feeding insects included (Table 60). The decline in spotted knapweed could have been due to drought, the impact of root-feeding insects, a combination of both, or some other unknown factor. It is hard to determine the cause of the decline because the knapweed feeders had spread to the control plots during the four years and, thus, made it difficult to determine impacts due to insects. After four years, sideoats grama was the most abundant species.

Table 60. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	81.2	70.2	93.5	133.5	222.4
Twistspine pricklypear	3.6	4.0	5.0	6.3	7.9
Soapweed	3.1	3.5	5.5	8.8	12.5
Crested wheatgrass	0.0	0.1	0.4	1.0	1.7
Western wheatgrass	0.3	0.4	2.0	8.4	27.4
Purple threeawn	13.1	4.3	5.6	6.9	8.7
Sideoats grama	5.5	2.8	9.3	30.3	56.5
Blue grama	3.3	2.2	3.4	4.7	6.0
Kentucky bluegrass	0.1	0.3	0.9	2.4	5.1
Little bluestem	0.3	0.5	1.8	4.9	10.0
Sacaton	0.0	0.1	1.1	5.1	17.5
Sand dropseed	0.6	0.8	2.1	4.4	6.9
Green needlegrass	0.0	0.0	0.1	0.1	0.2
Ragweed	0.3	1.5	7.0	8.4	8.0
Spotted knapweed	33.1	24.6	37.9	19.1	5.2
Canada thistle	0.0	0.1	0.5	2.1	4.1
Bindweed	0.0	0.2	0.4	0.4	0.4
Scarlet beeblossum	0.4	0.5	1.0	1.2	1.3
Golden aster	0.0	0.1	0.8	3.4	9.7
Hoarhound	0.0	0.3	0.2	0.2	0.2
Alfalfa	0.0	0.1	0.5	1.6	2.5
Orange globemallow	0.2	1.1	3.1	9.7	21.4
Mignonette	0.0	0.3	0.6	0.1	0.0
Wavyleaf thistle	0.0	0.1	0.3	1.3	2.8
Sweetclover	17.2	20.5	3.2	0.7	0.1
Japanese brome	0.0	0.0	0.1	1.4	6.1
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.0	0.3	0.1	0.0	0.0
Bladderpod	0.0	0.7	0.1	0.0	0.0
Russian thistle	0.0	0.6	0.6	0.4	0.2
Tansymustard	0.1	0.2	0.0	0.0	0.0
Litter	80.0	129.9	289.2	316.5	207.1

Average accuracy was 56% for spotted knapweed, 48% for blue grama, 50% for western wheatgrass, and 52% for total aboveground biomass (Table 61).

Table 61. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site with biological control and a 4-year simulation.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	24.56	29.46	0.834
2001	37.91	48.35	0.784
2002	19.14	0.01	0.001
2003	5.16	3.27	0.634
Blue grama			
2000	2.77	2.17	0.784
2001	9.29	15.96	0.582
2002	30.35	3.44	0.113
2003	56.46	25.43	0.450
Western wheatgrass			
2000	0.43	0.31	0.721
2001	1.97	1.13	0.574
2002	8.40	0.19	0.023
2003	27.39	18.94	0.691
Total biomass			
2000	70.16	126.04	0.557
2001	93.50	124.30	0.752
2002	133.51	13.99	0.105
2003	222.37	148.81	0.669

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

In the 50-year simulation with biological control included, spotted knapweed had disappeared from all plots by Year 10 (Table 62). Western wheatgrass was the dominant species after 50 years, followed by soapweed, twistspine pricklypear, and sideoats grama.

Table 62. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control and a 4-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	81	70	483	810	962	1027	1074
Twistspine pricklypear	4	4	27	124	161	184	209
Soapweed	3	3	46	175	247	250	251
Crested wheatgrass	0	0	4	6	7	8	8
Western wheatgrass	0	0	138	249	304	353	383
Purple threeawn	13	4	13	15	16	16	17
Sideoats grama	5	3	120	136	138	150	149
Blue grama	3	2	10	11	14	15	18
Kentucky bluegrass	0	0	6	4	2	1	1
Little bluestem	0	0	10	9	9	8	7
Sacaton	0	0	40	36	26	12	5
Sand dropseed	1	1	6	3	1	1	0
Green needlegrass	0	0	0	0	0	0	0
Ragweed	0	1	4	2	1	1	1
Spotted knapweed	33	25	0	0	0	0	0
Canada thistle	0	0	8	6	6	5	5
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	1	1	0	0	0	0
Golden aster	0	0	25	23	18	12	9
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	2	1	1	0	0
Orange globemallow	0	1	13	2	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	7	8	10	10	12
Sweetclover	17	20	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	80	130	181	156	206	185	215

6.2.4 Treatment Combinations

In the four-year run with knapweed-feeding insects and seeding included, western wheatgrass was the dominant species, followed by sideoats grama (Table 63). Spotted knapweed increased in the second year and then decreased in the third and fourth years, much more than in the previous treatment with insects alone.

Table 63. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	71.5	64.3	99.3	152.9	245.4
Twistspine pricklypear	2.4	2.6	3.4	4.1	5.1
Soapweed	0.5	0.6	2.0	3.5	5.1
Crested wheatgrass	0.0	0.1	0.9	2.2	3.0
Western wheatgrass	1.4	1.9	9.3	37.6	83.2
Purple threeawn	8.5	3.0	4.0	4.8	5.6
Sideoats grama	5.4	2.8	9.4	23.4	38.1
Blue grama	0.5	0.5	1.8	3.5	3.6
Kentucky bluegrass	0.0	0.1	0.4	1.0	1.4
Little bluestem	1.2	1.0	2.9	8.2	14.5
Sacaton	0.0	0.2	2.2	10.8	25.4
Sand dropseed	1.0	1.1	2.8	6.1	8.5
Green needlegrass	0.0	0.0	0.1	0.1	0.2
Ragweed	0.4	1.6	7.1	8.4	7.3
Spotted knapweed	33.1	24.3	38.7	15.0	2.0
Canada thistle	0.0	0.1	0.5	1.7	2.4
Bindweed	0.0	0.2	0.4	0.4	0.3
Scarlet beeblossum	0.4	0.5	0.9	1.0	1.1
Golden aster	0.0	0.1	0.8	3.2	6.2
Hoarhound	0.0	0.2	0.2	0.2	0.2
Alfalfa	0.0	0.1	0.7	1.7	2.1
Orange globemallow	0.1	0.9	2.6	6.5	8.7
Mignonette	0.0	0.3	0.5	0.1	0.0
Wavyleaf thistle	0.2	0.5	2.4	6.7	11.7
Sweetclover	16.4	19.6	4.3	0.9	0.1
Japanese brome	0.0	0.0	0.1	1.5	9.4
Lambsquarters	0.0	0.2	0.0	0.0	0.0
Sunflower	0.1	0.3	0.1	0.0	0.0
Bladderpod	0.0	0.7	0.1	0.0	0.0
Russian thistle	0.0	0.6	0.6	0.3	0.1
Tansymustard	0.0	0.1	0.0	0.0	0.0
Litter	86.1	132.5	307.0	323.6	196.2

Average accuracy was 40% for spotted knapweed, 51% for blue grama, 44% for western wheatgrass, and 51% for total aboveground biomass (Table 64).

Table 64. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site with biological control, seeding and a 4-year simulation.

Variable	Predicted	Sampled	Ratio
Spotted knapweed			
2000	24.32	29.16	0.834
2001	38.68	64.35	0.601
2002	15.02	0.16	0.011
2003	1.96	0.27	0.138
Blue grama			
2000	2.75	4.35	0.633
2001	9.41	14.98	0.628
2002	23.38	3.5	0.150
2003	38.07	23.31	0.612
Western wheatgrass			
2000	1.90	1.15	0.607
2001	9.28	8.72	0.940
2002	37.59	0.72	0.019
2003	83.22	16.84	0.202
Total biomass			
2000	64.33	108.52	0.593
2001	99.27	152.59	0.651
2002	152.86	13.16	0.086
2003	245.36	170.18	0.694

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

By Year 10, spotted knapweed had disappeared from the plots with knapweed-feeding insects and seeding (Table 65). At the end of the 50-year simulation, western wheatgrass, soapweed, sideoats grama, and twistspine pricklypear were the dominant species on the plots. The results of this simulation was very similar to the simulation that included only biological control.

Table 65. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	72	64	497	753	955	1037	1078
Twistspine pricklypear	2	3	17	60	95	116	141
Soapweed	1	1	17	76	223	250	251
Crested wheatgrass	0	0	6	7	6	6	5
Western wheatgrass	1	2	219	333	348	361	360
Purple threeawn	8	3	8	8	8	8	8
Sideoats grama	5	3	86	120	136	170	192
Blue grama	1	1	4	3	3	3	3
Kentucky bluegrass	0	0	2	1	0	0	0
Little bluestem	1	1	34	49	54	57	58
Sacaton	0	0	40	30	19	8	3
Sand dropseed	1	1	9	6	3	1	1
Green needlegrass	0	0	0	0	0	0	0
Ragweed	0	2	3	2	1	1	1
Spotted knapweed	33	24	0	0	0	0	0
Canada thistle	0	0	3	3	2	2	2
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	1	1	0	0	0	0
Golden aster	0	0	11	9	7	5	3
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	1	1	1	0	0
Orange globemallow	0	1	4	1	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	31	46	47	49	51
Sweetclover	16	20	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	86	133	188	156	200	187	220

When root-feeding insects and sugar application were included in the model, western wheatgrass was the dominant species at the end of the four-year simulation (Table 66). Spotted knapweed declined in a similar manner with this treatment combination and the treatment with biological control and seeding. Both sugar application and seeding favor growth of perennial species that will compete with knapweed for resources.

Table 66. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, sugar application and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	88.8	70.0	85.3	53.8	74.5
Twistspine pricklypear	1.9	2.1	2.7	3.3	4.1
Soapweed	0.7	0.8	2.1	3.1	4.0
Crested wheatgrass	0.0	0.1	0.2	0.2	0.2
Western wheatgrass	0.5	0.8	2.3	4.6	16.2
Purple threeawn	0.5	0.8	1.6	1.6	1.5
Sideoats grama	2.6	1.4	3.6	7.5	13.4
Blue grama	0.0	0.2	0.2	0.2	0.2
Kentucky bluegrass	0.0	0.1	0.3	0.6	0.9
Little bluestem	0.1	0.4	1.0	1.5	2.0
Sacaton	0.0	0.2	1.8	4.8	6.8
Sand dropseed	0.4	0.6	1.1	1.1	1.5
Green needlegrass	0.0	0.0	0.1	0.1	0.2
Ragweed	0.1	1.3	6.6	5.3	4.1
Spotted knapweed	72.7	46.8	53.7	10.9	1.2
Canada thistle	0.0	0.1	0.2	0.3	0.5
Bindweed	0.0	0.2	0.3	0.2	0.1
Scarlet beeblossum	0.4	0.5	0.7	0.7	0.7
Golden aster	0.0	0.1	0.6	2.2	3.8
Hoarhound	0.0	0.2	0.2	0.1	0.1
Alfalfa	0.0	0.1	0.4	2.0	9.1
Orange globemallow	0.2	1.0	2.2	2.5	2.7
Mignonette	0.0	0.3	0.5	0.1	0.0
Wavyleaf thistle	0.0	0.1	0.3	0.3	0.6
Sweetclover	8.2	9.9	2.0	0.5	0.1
Japanese brome	0.0	0.0	0.2	0.3	0.4
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.2	0.3	0.1	0.0	0.0
Bladderpod	0.0	0.7	0.1	0.0	0.0
Russian thistle	0.0	0.6	0.3	0.0	0.0
Tansymustard	0.2	0.2	0.0	0.0	0.0
Litter	97.0	154.6	325.2	390.2	417.2

Average accuracy was 50% for spotted knapweed, 55% for blue grama, 51% for western wheatgrass, and 57% for total biomass (Table 67).

Table 67. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site with biological control, sugar application and a 4-year simulation.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	46.79	52.27	0.895
2001	53.66	63.53	0.845
2002	10.91	0.94	0.086
2003	1.24	6.80	0.182
Blue grama			
2000	1.36	2.05	0.661
2001	3.62	8.61	0.420
2002	7.50	1.68	0.224
2003	13.37	12.05	0.901
Western wheatgrass			
2000	0.79	1.28	0.617
2001	2.33	6.21	0.376
2002	4.56	0.77	0.169
2003	16.23	14.45	0.890
Total biomass			
2000	70.01	95.15	0.736
2001	85.33	106.72	0.800
2002	53.81	9.54	0.177
2003	74.45	131.31	0.567

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

At the end of the 50-year run, sideoats grama was the dominant species on the plots, followed by soapweed, twistspine pricklypear, and western wheatgrass (Table 68). These plots produced different results after 50 years than the previous three treatment combinations, perhaps because application of sugar decreases available nitrogen and allowed sideoats grama to out-compete western wheatgrass.

Table 68. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, sugar application and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	70	414	705	989	1036	1063
Twistspine pricklypear	2	2	15	89	232	249	249
Soapweed	1	1	22	124	217	245	251
Crested wheatgrass	0	0	1	1	1	1	1
Western wheatgrass	1	1	108	180	206	201	204
Purple threeawn	0	1	1	1	0	0	0
Sideoats grama	3	1	108	179	225	265	295
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	4	3	2	1	1
Little bluestem	0	0	5	4	4	4	3
Sacaton	0	0	24	17	12	5	2
Sand dropseed	0	1	4	3	1	1	0
Green needlegrass	0	0	0	0	0	0	0
Ragweed	0	1	2	1	1	0	0
Spotted knapweed	73	47	0	0	0	0	0
Canada thistle	0	0	3	3	4	3	3
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	1	0	0	0	0
Golden aster	0	0	43	52	45	31	25
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	55	38	27	17	11
Orange globemallow	0	1	2	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	5	8	11	12	16
Sweetclover	8	10	0	0	0	0	0
Japanese brome	0	0	10	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	97	155	174	148	199	176	209

Spotted knapweed increased in the second year and declined in the third and fourth years of the simulation when knapweed-feeding insects, seeding, and sugar application were included (Table 69). By the fourth year, very little knapweed biomass remained and western wheatgrass, sideoats grama, and sacaton dominated the plots.

Table 69. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding, sugar application and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	54.7	48.6	80.7	72.9	131.6
Twistspine pricklypear	1.9	2.0	2.6	3.2	4.0
Soapweed	0.3	0.4	1.6	2.3	3.0
Crested wheatgrass	0.0	0.1	0.7	0.8	1.1
Western wheatgrass	0.8	1.1	3.9	9.2	31.4
Purple threeawn	5.1	2.1	3.2	3.3	3.4
Sideoats grama	3.8	1.9	5.4	10.1	19.5
Blue grama	0.4	0.4	1.6	3.0	2.9
Kentucky bluegrass	0.2	0.3	1.1	2.0	3.6
Little bluestem	1.4	1.1	3.3	5.1	8.4
Sacaton	0.3	0.5	4.2	9.3	19.0
Sand dropseed	0.1	0.5	1.2	1.2	1.4
Green needlegrass	0.0	0.0	0.1	0.1	0.2
Ragweed	0.1	1.2	7.1	5.6	4.3
Spotted knapweed	33.1	24.3	34.7	5.8	0.7
Canada thistle	0.0	0.1	0.3	0.4	0.6
Bindweed	0.0	0.2	0.3	0.3	0.2
Scarlet beeblossum	0.8	0.9	1.2	1.3	1.3
Golden aster	0.0	0.1	0.7	2.0	3.7
Hoarhound	0.0	0.2	0.2	0.1	0.1
Alfalfa	0.0	0.1	0.7	3.9	18.9
Orange globemallow	0.0	0.7	1.6	2.0	2.1
Mignonette	0.0	0.3	0.7	0.2	0.0
Wavyleaf thistle	0.0	0.2	0.4	0.4	0.7
Sweetclover	6.3	7.7	2.5	0.6	0.1
Japanese brome	0.0	0.1	0.8	0.9	1.2
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.2	0.4	0.1	0.0	0.0
Bladderpod	0.0	0.7	0.1	0.0	0.0
Russian thistle	0.0	0.5	0.2	0.0	0.0
Tansymustard	0.0	0.1	0.0	0.0	0.0
Litter	91.7	127.3	285.5	339.2	346.6

Average accuracy was 50% for spotted knapweed, 45% for blue grama, 47% for western wheatgrass, and 58% for total biomass (Table 70).

Table 70. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site with biological control, seeding, sugar application and a 4-year simulation.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	24.33	25.52	0.953
2001	34.67	27.04	0.780
2002	5.79	0.09	0.016
2003	0.66	2.48	0.267
Blue grama			
2000	1.95	7.51	0.259
2001	5.38	13.32	0.404
2002	10.07	2.72	0.270
2003	19.51	16.91	0.867
Western wheatgrass			
2000	1.10	2.87	0.383
2001	3.89	7.11	0.548
2002	9.23	0.48	0.052
2003	31.38	34.56	0.908
Total biomass			
2000	48.55	80.14	0.606
2001	80.66	95.20	0.847
2002	72.92	7.68	0.105
2003	131.65	102.15	0.776

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

When insects, seed, and sugar application were included together in the simulation, knapweed disappeared by Year 10. The dominant vegetation in these plots was more diverse than previous treatment combinations, with western wheatgrass, soapweed, little bluestem, twistspine pricklypear, and sideoats grama having the most biomass (Table 71).

Table 71. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding, sugar application and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	55	49	482	756	957	1067	1131
Twistspine pricklypear	2	2	13	66	105	116	161
Soapweed	0	0	12	54	166	245	251
Crested wheatgrass	0	0	3	4	4	3	3
Western wheatgrass	1	1	192	286	311	319	320
Purple threeawn	5	2	6	6	7	7	8
Sideoats grama	4	2	60	79	84	107	136
Blue grama	0	0	3	2	1	1	1
Kentucky bluegrass	0	0	18	23	19	15	16
Little bluestem	1	1	58	112	146	182	198
Sacaton	0	1	75	98	95	60	29
Sand dropseed	0	0	2	1	0	0	0
Green needlegrass	0	0	0	0	0	0	0
Ragweed	0	1	2	1	1	0	0
Spotted knapweed	33	24	0	0	0	0	0
Canada thistle	0	0	1	1	1	0	0
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	1	1	1	0	0	0	0
Golden aster	0	0	11	9	6	4	3
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	22	13	8	5	3
Orange globemallow	0	1	1	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	2	2	2	1	1
Sweetclover	6	8	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	92	127	188	159	205	186	225

Western wheatgrass and sideoats grama were the most prevalent species at the end of four years on the plots simulated with knapweed-feeding insects, seeding, and soil inoculation (Table 72). Spotted knapweed increased in Year 2 and then declined to about 3 g/m^2 by Year 4.

Table 72. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding, inoculation and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	67.1	65.2	101.9	145.7	240.0
Twistspine pricklypear	0.6	0.7	1.1	1.4	1.8
Soapweed	7.3	8.0	11.1	16.7	24.5
Crested wheatgrass	0.0	0.1	0.9	2.3	3.7
Western wheatgrass	1.5	2.1	10.2	26.1	66.4
Purple threeawn	2.7	1.5	2.3	2.7	3.3
Sideoats grama	4.3	2.2	7.7	22.1	37.7
Blue grama	1.4	1.0	2.7	4.7	5.5
Kentucky bluegrass	0.1	0.3	0.8	1.7	2.9
Little bluestem	0.3	0.5	1.6	4.5	9.1
Sacaton	0.0	0.0	0.1	1.0	3.0
Sand dropseed	0.1	0.5	1.4	3.1	4.5
Green needlegrass	0.0	0.0	0.1	0.1	0.2
Ragweed	0.6	1.7	7.5	8.7	8.1
Spotted knapweed	33.1	24.5	39.2	17.4	2.8
Canada thistle	0.2	0.4	2.0	8.0	15.1
Bindweed	0.0	0.2	0.4	0.4	0.4
Scarlet beeblossum	0.4	0.5	0.9	1.1	1.2
Golden aster	0.0	0.1	0.8	3.3	9.0
Hoarhound	0.0	0.2	0.2	0.2	0.2
Alfalfa	0.0	0.1	0.7	2.2	3.3
Orange globemallow	0.1	0.9	2.6	7.1	14.4
Mignonette	0.0	0.3	0.5	0.1	0.0
Wavyleaf thistle	0.1	0.2	1.1	4.3	8.6
Sweetclover	13.9	16.8	3.9	0.7	0.1
Japanese brome	0.0	0.1	1.0	5.5	14.1
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.0	0.3	0.1	0.0	0.0
Bladderpod	0.3	1.1	0.4	0.0	0.0
Russian thistle	0.0	0.6	0.6	0.3	0.2
Tansymustard	0.0	0.1	0.0	0.0	0.0
Litter	88.3	127.8	293.6	291.9	185.5

Average accuracy was 51% for spotted knapweed, 52% for blue grama, 37% for western wheatgrass, and 60% for total biomass (Table 73).

Table 73. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site with biological control, seeding, inoculation and a 4-year simulation.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	24.46	21.00	0.859
2001	39.20	48.18	0.814
2002	17.36	0.66	0.038
2003	2.85	9.01	0.316
Blue grama			
2000	2.22	3.46	0.643
2001	7.70	8.07	0.954
2002	22.15	2.36	0.107
2003	37.70	14.76	0.392
Western wheatgrass			
2000	2.11	5.55	0.381
2001	10.21	12.38	0.824
2002	26.14	0.55	0.021
2003	66.37	17.49	0.264
Total biomass			
2000	65.22	87.06	0.749
2001	101.87	119.32	0.854
2002	145.72	26.52	0.182
2003	240.01	145.19	0.605

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

Western wheatgrass, soapweed, twistspine pricklypear, sideoats grama, and little bluestem were the dominant species after 50 years on plots simulated with knapweed-feeding insects, seeding, and soil inoculation (Table 74). Spotted knapweed had disappeared by Year 10.

Table 74. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding, inoculation and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	67	65	506	757	972	1054	1118
Twistspine pricklypear	1	1	6	38	109	126	167
Soapweed	7	8	90	140	227	250	250
Crested wheatgrass	0	0	10	16	18	18	17
Western wheatgrass	2	2	169	267	289	293	293
Purple threeawn	3	1	4	4	4	4	4
Sideoats grama	4	2	78	104	117	129	135
Blue grama	1	1	9	11	13	14	16
Kentucky bluegrass	0	0	4	2	1	1	0
Little bluestem	0	1	28	58	83	107	118
Sacaton	0	0	7	6	4	2	1
Sand dropseed	0	0	3	1	1	0	0
Green needlegrass	0	0	0	0	0	0	0
Ragweed	1	2	4	2	1	1	1
Spotted knapweed	33	24	0	0	0	0	0
Canada thistle	0	0	34	44	46	47	49
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	1	0	0	0	0
Golden aster	0	0	22	21	16	11	8
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	3	2	1	1	0
Orange globemallow	0	1	9	1	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	24	35	42	49	57
Sweetclover	14	17	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	88	128	177	165	209	189	224

When insects, sugar application, and soil inoculation were included together, spotted knapweed increased in the second year and decreased in the third and fourth years, as it did in most of the previous simulations (Table 75). At the end of the four-year simulation, western wheatgrass and sideoats grama were the dominant species.

Table 75. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, sugar application, inoculation and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	76.1	68.2	85.9	89.0	183.2
Twistspine pricklypear	0.7	0.8	1.1	1.4	1.7
Soapweed	0.5	0.7	2.0	2.8	3.7
Crested wheatgrass	0.0	0.1	0.2	0.2	0.3
Western wheatgrass	1.8	2.5	7.7	15.3	61.6
Purple threeawn	6.2	2.4	3.4	3.6	3.9
Sideoats grama	9.4	4.7	12.1	23.0	45.8
Blue grama	1.1	0.8	0.9	0.8	1.2
Kentucky bluegrass	0.5	0.7	1.8	3.2	6.2
Little bluestem	2.0	1.4	3.9	6.5	11.2
Sacaton	0.0	0.2	1.9	5.1	9.2
Sand dropseed	1.0	1.1	1.8	1.8	2.7
Green needlegrass	0.0	0.0	0.1	0.1	0.2
Ragweed	0.3	1.5	6.5	5.2	4.1
Spotted knapweed	33.1	24.4	31.7	5.8	0.7
Canada thistle	0.0	0.1	0.3	0.4	0.7
Bindweed	0.0	0.2	0.3	0.2	0.2
Scarlet beeblossum	0.7	0.8	1.1	1.1	1.1
Golden aster	0.0	0.1	0.7	2.3	4.7
Hoarhound	0.0	0.2	0.2	0.1	0.1
Alfalfa	0.0	0.1	0.4	1.9	7.2
Orange globemallow	0.1	0.8	1.7	2.1	2.6
Mignonette	0.0	0.3	0.6	0.1	0.0
Wavyleaf thistle	0.0	0.2	0.3	0.4	0.8
Sweetclover	18.3	21.9	3.8	0.9	0.2
Japanese brome	0.0	0.1	1.0	4.8	13.3
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.2	0.4	0.1	0.0	0.0
Bladderpod	0.1	0.8	0.2	0.0	0.0
Russian thistle	0.2	0.6	0.2	0.0	0.0
Tansymustard	0.0	0.1	0.0	0.0	0.0
Litter	76.7	127.2	290.4	317.8	278.2

Average accuracy was 53% for spotted knapweed, 49% for blue grama, 37% for western wheatgrass, and 59% for total biomass (Table 76).

Table 76. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site with biological control, sugar application, inoculation and a 4-year simulation.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	24.42	23.82	0.975
2001	31.68	39.11	0.810
2002	5.82	0.64	0.110
2003	0.66	3.17	0.207
Blue grama			
2000	4.68	7.56	0.619
2001	12.07	10.60	0.878
2002	23.01	2.35	0.102
2003	45.83	17.42	0.380
Western wheatgrass			
2000	2.46	6.97	0.354
2001	7.68	15.40	0.498
2002	15.31	1.18	0.077
2003	61.56	32.99	0.536
Total biomass			
2000	68.15	92.56	0.736
2001	85.87	109.27	0.786
2002	88.98	8.66	0.097
2003	183.17	134.73	0.736

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

At the end of the 50-year simulation with biological control, sugar application, and soil inoculation, western wheatgrass, soapweed, sideoats grama, and twistspine pricklypear were the dominant species on these plots (Table 77).

Table 77. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, sugar application, inoculation and a 50-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	76	68	445	671	934	1007	1042
Twistspine pricklypear	1	1	6	39	149	156	168
Soapweed	1	1	14	72	201	249	251
Crested wheatgrass	0	0	1	1	1	1	0
Western wheatgrass	2	2	160	244	278	291	297
Purple threeawn	6	2	6	7	7	7	8
Sideoats grama	9	5	144	201	203	226	240
Blue grama	1	1	2	1	1	1	1
Kentucky bluegrass	1	1	9	6	4	3	5
Little bluestem	2	1	30	41	45	46	50
Sacaton	0	0	19	14	9	4	2
Sand dropseed	1	1	2	1	0	0	0
Green needlegrass	0	0	0	0	0	0	0
Ragweed	0	1	2	1	1	0	0
Spotted knapweed	33	24	0	0	0	0	0
Canada thistle	0	0	2	1	1	1	1
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	1	1	1	0	0	0	0
Golden aster	0	0	22	25	20	13	11
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	22	14	10	6	4
Orange globemallow	0	1	1	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	2	3	3	3	3
Sweetclover	18	22	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	77	127	180	151	193	180	211

When all four treatments were included together in a four-year simulation, western wheatgrass and sideoats grama were the dominant species at the end of four years (Table 78). Spotted knapweed increased in the second year and decreased in the third and fourth years.

Table 78. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding, sugar application, inoculation and a 4-year simulation run.

Species	June Aboveground Biomass (g/m^2)				
	Initial	Year 1	Year 2	Year 3	Year 4
Total	70.6	66.7	93.0	86.2	165.4
Twistspine pricklypear	2.8	3.0	3.8	4.7	5.8
Soapweed	0.0	0.1	1.3	1.7	2.3
Crested wheatgrass	0.0	0.1	0.7	0.7	0.9
Western wheatgrass	3.3	4.6	17.5	26.3	79.7
Purple threeawn	1.0	1.0	1.5	1.5	1.5
Sideoats grama	5.8	2.9	7.6	15.3	29.0
Blue grama	0.0	0.2	1.3	2.2	2.0
Kentucky bluegrass	0.1	0.3	0.7	1.0	1.6
Little bluestem	0.0	0.3	0.7	1.1	1.2
Sacaton	0.0	0.2	1.9	4.6	7.0
Sand dropseed	0.6	0.8	1.5	1.5	2.2
Green needlegrass	1.8	1.0	1.3	1.5	1.9
Ragweed	0.2	1.4	6.2	4.9	3.9
Spotted knapweed	39.7	28.4	35.3	6.3	0.7
Canada thistle	0.0	0.1	0.3	0.3	0.6
Bindweed	0.0	0.2	0.3	0.2	0.2
Scarlet beeblossum	0.1	0.3	0.5	0.5	0.5
Golden aster	0.0	0.1	0.7	2.2	4.1
Hoarhound	0.0	0.2	0.2	0.1	0.1
Alfalfa	0.0	0.1	0.7	2.9	13.1
Orange globemallow	0.6	1.7	3.8	4.1	5.5
Mignonette	0.0	0.3	0.5	0.1	0.0
Wavyleaf thistle	0.0	0.2	0.5	0.7	1.5
Sweetclover	14.1	17.0	3.3	0.6	0.1
Japanese brome	0.0	0.1	0.6	1.0	0.0
Lambsquarters	0.0	0.1	0.0	0.0	0.0
Sunflower	0.4	0.4	0.1	0.0	0.0
Bladderpod	0.0	0.8	0.1	0.0	0.0
Russian thistle	0.0	0.6	0.2	0.0	0.0
Tansymustard	0.0	0.1	0.0	0.0	0.0
Litter	70.7	115.6	290.5	325.5	307.5

Average accuracy was 52% for spotted knapweed, 55% for blue grama, 43% for western wheatgrass, and 67% for total aboveground biomass (Table 79).

Table 79. Percent accuracy for the four-year modelling run for the Fort Carson knapweed site with biological control, seeding, sugar application, inoculation and a 4-year simulation.

Variable	Predicted	Sampled	Accuracy
Spotted knapweed			
2000	28.37	38.17	0.743
2001	35.34	50.51	0.700
2002	6.33	0.00	0.000
2003	0.72	1.13	0.635
Blue grama			
2000	2.93	5.69	0.515
2001	7.58	13.33	0.568
2002	15.34	2.12	0.138
2003	29.01	30.20	0.961
Western wheatgrass			
2000	4.55	4.01	0.881
2001	17.47	5.19	0.297
2002	26.34	1.07	0.041
2003	79.65	40.83	0.513
Total biomass			
2000	66.73	75.11	0.888
2001	92.98	121.48	0.765
2002	86.19	6.77	0.079
2003	165.40	174.91	0.946

Note: Sample and predicted values are biomass values (g/m^2) for the respective dates. Accuracy is calculated by dividing the smaller of the predicted or sampled value by the larger.

After 50 years, the dominant species in the plots simulated with all four treatments together were western wheatgrass, sideoats grama, soapweed, and twistspine pricklypear. These results are very similar to most of the other 50-year results and, thus, it appears that regardless of treatment perennial grasses, soapweed, and twistspine pricklypear will be the dominant species over the long term. If the treatments were applied at a higher intensity or more frequently, an effect might be seen in the long term (Table 80).

Table 80. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed site, with biological control, seeding, sugar application, inoculation and a 4-year simulation.

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	71	67	467	728	938	1030	1058
Twistspine pricklypear	3	3	20	127	176	203	208
Soapweed	0	0	10	42	172	239	251
Crested wheatgrass	0	0	3	4	4	3	3
Western wheatgrass	3	5	207	290	310	286	284
Purple threeawn	1	1	2	1	1	1	1
Sideoats grama	6	3	148	210	232	266	282
Blue grama	0	0	2	1	0	0	0
Kentucky bluegrass	0	0	3	2	2	2	1
Little bluestem	0	0	2	1	1	1	0
Sacaton	0	0	17	10	6	3	1
Sand dropseed	1	1	3	2	1	0	0
Green needlegrass	2	1	2	2	2	2	2
Ragweed	0	1	2	1	1	0	0
Spotted knapweed	40	28	0	0	0	0	0
Canada thistle	0	0	2	1	1	1	1
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	0	0	0	0	0
Golden aster	0	0	16	14	11	7	6
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	21	11	7	4	3
Orange globemallow	1	2	3	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	5	7	9	10	15
Sweetclover	14	17	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	71	116	181	148	185	174	209

6.2.5 Herbivory

With light herbivory (3 insects/m^2 and 0.30 rabbits/m^2), total biomass at Year 50 was 21% lower than with no herbivory (Table 81). No changes were seen in the succulents because they are not a preferred species of the herbivores (Appendix Table 25). Biomass of western wheatgrass was 51% lower in plots with herbivory than in those without herbivory. Herbivores also negatively affected growth of Kentucky bluegrass. Growth of spotted knapweed was not really affected by the herbivory. Growth of green needlegrass actually increased about 50%.

Table 81. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with light herbivory from insects (3 per m^2) and rabbits (0.30 per m^2)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	54	392	589	775	817	877
Twistspine pricklypear	2	2	14	68	105	114	140
Soapweed	5	5	27	119	249	251	251
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	5	3	58	150	210	267	309
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	1	0	1	1	1	1	1
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	6	7	137	147	138	139	138
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	72	41	20	7	3
Sand dropseed	2	1	0	0	0	0	0
Green needlegrass	30	12	13	13	14	14	14
Ragweed	0	1	1	1	1	0	0
Spotted knapweed	33	16	0	0	0	0	0
Canada thistle	0	0	12	7	5	3	3
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	1	0	0	0	0
Golden aster	0	0	36	25	17	10	8
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	1	1	1	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	21	16	14	11	11
Sweetclover	4	3	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	103	153	145	116	162	144	166

With moderate herbivory (6 insects/m^2 and 0.56 rabbits/m^2) total biomass was about 35% lower than without herbivory (Table 82). Biomass of twistspine pricklypear and soapweed were reduced 11 and 79%, respectively. Western wheatgrass biomass was 49% lower than in plots without herbivory. Kentucky bluegrass biomass, golden aster, and wavyleaf thistle were the only species that had greater biomass over the plots without herbivory, probably because preference for these species is lower than that of other species.

Table 82. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with medium herbivory from insects (6 per m^2) and rabbits (0.56 per m^2)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	49	366	525	638	670	719
Twistspine pricklypear	2	2	13	65	101	104	116
Soapweed	5	4	8	21	52	52	52
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	5	2	32	133	214	284	325
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	1	0	0	0	0	0	1
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	6	7	124	151	152	150	146
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	49	34	19	7	3
Sand dropseed	2	1	0	0	0	0	0
Green needlegrass	30	11	12	12	12	12	12
Ragweed	0	0	0	0	0	0	0
Spotted knapweed	33	15	0	0	0	0	0
Canada thistle	0	0	20	13	9	6	6
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	1	0	0	0	0
Golden aster	0	0	65	56	39	26	21
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	1	1	0	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	41	40	37	27	36
Sweetclover	4	3	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	103	150	139	114	151	120	153

With heavy herbivory (6 insects/m^2 and 0.56 rabbits/m^2) total biomass was about 27% lower than without herbivory (Table 83). Biomass of twistspine pricklypear and soapweed were both reduced 19 and 79%, respectively. Western wheatgrass biomass was 45% lower and Kentucky bluegrass biomass was 60% lower. Sideoats grama and green needlegrass were the only species that had greater biomass over the plots without herbivory, probably because preference for these species is lower than that of other species.

Table 83. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with heavy herbivory from insects (12 per m^2) and rabbits (0.78 per m^2)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	45	411	595	691	742	807
Twistspine pricklypear	2	2	12	64	100	101	105
Soapweed	5	4	5	7	12	32	52
Crested wheatgrass	0	0	0	0	0	0	0
Western wheatgrass	5	2	35	126	215	294	349
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	1	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	6	5	58	89	100	97	89
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	28	25	11	4	2
Sand dropseed	2	1	0	0	0	0	0
Green needlegrass	30	11	12	12	12	12	12
Ragweed	0	0	0	0	0	0	0
Spotted knapweed	33	15	0	0	0	0	0
Canada thistle	0	0	39	29	22	14	12
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	1	0	0	0	0
Golden aster	0	0	124	127	96	74	55
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	1	1	0	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	94	114	121	113	130
Sweetclover	4	1	0	0	0	0	0
Japanese brome	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	103	147	145	116	151	114	154

6.2.6 Grazing

When impact of light grazing (64 Ac/AU) was included in the model, total aboveground biomass was only 3% higher than in ungrazed plots (Table 84). Western wheatgrass biomass increased 25% and it was the dominant species. Most other grasses and forbs were gone by the end of the simulation.

Table 84. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with light grazing (64 acres per animal unit)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	70	462	800	1000	1068	1143
Twistspine pricklypear	2	1	0	0	0	0	0
Soapweed	5	5	42	186	252	251	251
Crested wheatgrass	0	0	1	1	1	2	7
Western wheatgrass	5	7	350	563	704	766	790
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	1	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	6	5	15	5	0	0	0
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	0	0	0	0	0
Sand dropseed	2	1	0	0	0	0	0
Green needlegrass	30	17	34	33	34	35	36
Ragweed	0	1	2	1	1	0	0
Spotted knapweed	33	25	0	0	0	0	0
Canada thistle	0	0	1	1	0	0	0
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	1	0	0	0	0
Golden aster	0	0	14	9	6	13	58
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	1	1	0	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	2	1	1	0	0
Sweetclover	4	2	0	0	0	0	0
Japanese brome	0	1	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	103	153	167	145	207	197	200

When moderate grazing (32 Ac/AU) was included in the model, no differences were seen in long-term total aboveground biomass (Table 85). Vegetation composition was changed however. Western wheatgrass was the dominant species, as in the ungrazed plots. Most other grasses and forbs had disappeared by the end of the simulation.

Table 85. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with moderate grazing (32 acres per animal unit)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	72	448	782	969	1049	1136
Twistspine pricklypear	2	2	1	0	0	0	0
Soapweed	5	5	36	170	252	251	251
Crested wheatgrass	0	0	1	1	1	2	7
Western wheatgrass	5	7	338	554	671	749	789
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	1	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	6	6	23	13	4	1	0
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	0	0	0	0	0
Sand dropseed	2	1	0	0	0	0	0
Green needlegrass	30	17	35	34	35	36	37
Ragweed	0	1	2	1	0	0	0
Spotted knapweed	33	24	0	0	0	0	0
Canada thistle	0	0	1	1	0	0	0
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	1	0	0	0	0
Golden aster	0	0	8	6	4	10	51
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	1	1	1	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	2	1	1	1	0
Sweetclover	4	3	0	0	0	0	0
Japanese brome	0	1	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	103	153	168	142	203	197	201

When heavy grazing (21 Ac/AU) was included in the model, total aboveground biomass was 5% lower in grazed plots than in ungrazed plots. Western wheatgrass was the dominant species by Year 50 and its biomass was 14% higher than in ungrazed plots (Table 86).

Table 86. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with heavy grazing (21 acres per animal unit)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)						
	Initial	Year 1	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	75	420	711	903	975	1054
Twistspine pricklypear	2	2	1	0	0	0	0
Soapweed	5	5	33	158	252	251	251
Crested wheatgrass	0	0	1	1	1	1	5
Western wheatgrass	5	7	285	465	580	666	725
Purple threeawn	0	0	0	0	0	0	0
Sideoats grama	1	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0
Kentucky bluegrass	6	6	61	52	35	18	6
Little bluestem	0	0	0	0	0	0	0
Sacaton	0	0	0	0	0	0	0
Sand dropseed	2	1	0	0	0	0	0
Green needlegrass	30	17	31	30	31	32	33
Ragweed	0	1	2	1	0	0	0
Spotted knapweed	33	24	0	0	0	0	0
Canada thistle	0	0	1	0	0	0	0
Bindweed	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	0	0	0	0	0
Golden aster	0	0	3	2	2	6	34
Hoarhound	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0
Orange globemallow	1	1	1	0	0	0	0
Mignonette	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	1	1	1	1	1
Sweetclover	4	4	0	0	0	0	0
Japanese brome	0	1	1	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0
Litter	103	153	160	136	194	185	200

6.2.7 Military Training

When impacts of an M-1 Abrams tank passing through the plots in Year 5 were included in the model, there was no long-term change seen in vegetation biomass and species composition (Table 87). At Year 50, total aboveground biomass was only 2% lower in the plots with the tank passing through than in the undisturbed plots. Although total aboveground biomass decreased in Year 5, by Year 10 biomass was only 15% lower than in undisturbed plots.

Table 87. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with military training (M-1 Abrams tank training in Year 5)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	78	75	369	666	932	1025	1091
Twistspine pricklypear	2	2	4	14	68	103	111	132
Soapweed	5	5	3	13	76	251	251	251
Crested wheatgrass	0	0	0	1	1	1	1	1
Western wheatgrass	5	7	28	230	408	482	569	616
Purple threeawn	0	1	0	0	0	0	0	0
Sideoats grama	1	1	2	8	10	13	25	38
Blue grama	0	0	0	0	0	0	0	0
Kentucky bluegrass	6	7	18	74	79	61	46	32
Little bluestem	0	0	0	0	0	0	0	0
Sacaton	0	0	1	1	0	0	0	0
Sand dropseed	2	2	1	3	2	1	1	1
Green needlegrass	30	17	11	16	16	17	17	17
Ragweed	0	1	1	2	1	1	1	1
Spotted knapweed	33	24	2	0	0	0	0	0
Canada thistle	0	0	0	1	1	1	1	1
Bindweed	0	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	0	0	0	0	0	0
Golden aster	0	0	0	1	1	1	1	1
Hoarhound	0	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0	0
Orange globemallow	1	2	1	1	0	0	0	0
Mignonette	0	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	0	1	1	1	1	2
Sweetclover	4	5	0	0	0	0	0	0
Japanese brome	0	1	1	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0	0
Litter	103	154	363	163	137	184	175	205

When impacts of the M-1 Abrams tank passing through the plots every five years were included in the model, total aboveground biomass was 74% lower at Year 50 than in undisturbed plots. Species composition was also negatively affected. Biomass of twistspine pricklypear was 23% lower, soapweed was 95% lower and western wheatgrass was 75% lower than in undisturbed plots. By the end of the simulation, no forbs or annual grasses were present (Table 88).

Table 88. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with military training (M-1 Abrams tank training every 5 years)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	78	75	151	210	267	260	290
Twistspine pricklypear	2	2	4	12	55	88	92	100
Soapweed	5	5	3	3	3	5	7	12
Crested wheatgrass	0	0	0	0	0	0	0	0
Western wheatgrass	5	7	28	81	109	138	135	157
Purple threeawn	0	1	0	0	0	0	0	0
Sideoats grama	1	1	2	4	5	5	5	6
Blue grama	0	0	0	0	0	0	0	0
Kentucky bluegrass	6	7	18	39	35	28	19	15
Little bluestem	0	0	0	0	0	0	0	0
Sacaton	0	0	1	1	0	0	0	0
Sand dropseed	2	2	1	1	0	0	0	0
Green needlegrass	30	17	11	7	2	1	0	0
Ragweed	0	1	1	0	0	0	0	0
Spotted knapweed	33	24	2	0	0	0	0	0
Canada thistle	0	0	0	1	0	0	0	0
Bindweed	0	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	0	0	0	0	0	0
Golden aster	0	0	0	0	0	0	0	0
Hoarhound	0	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0	0
Orange globemallow	1	2	1	0	0	0	0	0
Mignonette	0	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	0	0	0	0	0	0
Sweetclover	4	5	0	0	0	0	0	0
Japanese brome	0	1	1	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0	0
Litter	103	154	363	276	292	318	329	346

When impacts of a HMMWV passing through the plots every five years were included in the model, the long-term results were identical to those for the M-1 Abrams tank. Although these two vehicles do not have the same "footprint", the cumulative impacts to vegetation are the same (Table 89).

Table 89. EDYS simulation of vegetation dynamics at the Fort Carson Landscape knapweed control site with military training (HMMWV training every 5 years)(mean of 5 plots).

Species	June Aboveground Biomass (g/m^2)							
	Initial	Year 1	Year 5	Year 10	Year 20	Year 30	Year 40	Year 50
Total	89	78	75	151	210	267	260	290
Twistspine pricklypear	2	2	4	12	55	88	92	100
Soapweed	5	5	3	3	3	5	7	12
Crested wheatgrass	0	0	0	0	0	0	0	0
Western wheatgrass	5	7	28	81	109	138	135	157
Purple threeawn	0	1	0	0	0	0	0	0
Sideoats grama	1	1	2	4	5	5	5	6
Blue grama	0	0	0	0	0	0	0	0
Kentucky bluegrass	6	7	18	39	35	28	19	15
Little bluestem	0	0	0	0	0	0	0	0
Sacaton	0	0	1	1	0	0	0	0
Sand dropseed	2	2	1	1	0	0	0	0
Green needlegrass	30	17	11	7	2	1	0	0
Ragweed	0	1	1	0	0	0	0	0
Spotted knapweed	33	24	2	0	0	0	0	0
Canada thistle	0	0	0	1	0	0	0	0
Bindweed	0	0	0	0	0	0	0	0
Scarlet beeblossum	0	0	0	0	0	0	0	0
Golden aster	0	0	0	0	0	0	0	0
Hoarhound	0	0	0	0	0	0	0	0
Alfalfa	0	0	0	0	0	0	0	0
Orange globemallow	1	2	1	0	0	0	0	0
Mignonette	0	0	0	0	0	0	0	0
Wavyleaf thistle	0	0	0	0	0	0	0	0
Sweetclover	4	5	0	0	0	0	0	0
Japanese brome	0	1	1	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0	0
Bladderpod	0	1	0	0	0	0	0	0
Russian thistle	0	1	0	0	0	0	0	0
Tansymustard	0	0	0	0	0	0	0	0
Litter	103	154	363	276	292	318	329	346

6.2.5 Knapweed Modelling Summary

Spotted knapweed rapidly declined in this study, although the cause was not clear. The biocontrol insects, drought, or a combination of both could have caused the decline. In every plot except for the burned-only plots, western wheatgrass was the dominant species at the end of the four-year simulation (Table 90). The replacement of spotted knapweed by perennial grasses occurred in a very short period of time (four years), but these results are in agreement with succession studies in which weeds lose dominance under resource limitations in favor of more drought-adapted species such as perennials (McLendon and Redente 1994). After 50 years, western wheatgrass was the dominant species in all plots, except for the burned plots with sugar applied.

Table 90. Dominant vegetation species in the Fort Carson knapweed EDYS simulations after 4 and 50 years.

Treatment	Dominant Species	
	4 years	50 years
Control – Undisturbed	Western wheatgrass	Western wheatgrass Soapweed Twistspine pricklypear
Burned	Sideoats grama	Western wheatgrass Soapweed Twistspine pricklypear Sideoats grama
Burned, seeded	Western wheatgrass	Western wheatgrass Soapweed Sideoats grama Twistspine pricklypear
Burned, sugar application	Western wheatgrass Sideoats grama	Sideoats grama Soapweed Twistspine pricklypear Western wheatgrass
Burned, seeded, sugar application	Western wheatgrass Sideoats grama Sacaton Alfalfa	Western wheatgrass Soapweed Little bluestem Twistspine pricklypear Sideoats grama
Burned, seeded, inoculation	Western wheatgrass Sideoats grama	Western wheatgrass Soapweed Twistspine pricklypear Sideoats grama Little bluestem
Burned, sugar application, inoculation	Western wheatgrass Sideoats grama	Western wheatgrass Soapweed Sideoats grama Twistspine pricklypear
Burned, seeded, sugar application, inoculation	Western wheatgrass Sideoats grama	Western wheatgrass Sideoats grama Soapweed Twistspine pricklypear

Light levels of herbivory caused a decrease in perennial grasses and an increase in golden aster and wavyleaf thistle. The major species at the end of 50 years were western wheatgrass, twistspine pricklypear, soapweed, and Kentucky bluegrass whereas the same community without herbivory was dominated by western wheatgrass and the two succulents. With moderate herbivory, the major species at the end of fifty years were the same as with the light herbivory. Heavy herbivory caused a decrease in total aboveground biomass and significantly reduced the biomass of soapweed and perennial grasses. At the end of 50 years, the community was dominated by western wheatgrass, wavyleaf thistle and twistspine pricklypear.

When grazing was included in the model, no real impacts on vegetation total aboveground biomass were seen. Species composition was different at the end of the 50-year simulation. Twistspine pricklypear disappeared from the plots whereas in ungrazed plots it was a major species. Western wheatgrass biomass increased with all levels of grazing and, at the end of 50 years, it was the dominant species. Most other grasses and forbs were gone by the end of the simulation.

When impacts of an M-1 Abrams tank passing through the plots in Year 5 were included in the model, there was no long-term change seen in vegetation biomass and species composition. When impacts of an M-1 Abrams tank or a HMMWV passing through the plots every five years were included in the model, total aboveground biomass was 74% lower at Year 50 than in undisturbed plots. Species composition was also negatively affected. Biomass of twistspine pricklypear was 23% lower, soapweed was 95% lower and western wheatgrass was 75% lower than in undisturbed plots. By the end of the simulation, no forbs or annual grasses were present.

7.0 CONCLUSIONS

The EDYS model was able to simulate some trends in vegetation change that occurred in the brome site, but did not produce satisfactory results in many cases. At the knapweed site, the EDYS simulations reflected well the changes that occurred in the field during the four years of the validation period. At the brome site, Japanese brome was the dominant species at the beginning of the study, but four years later the production of this species had drastically declined. The drought conditions of 2002 and 2003 were a main reason for this effect. The EDYS model did not simulate well this decline in Japanese brome, likely because the precipitation data that was used for modeling did not represent accurately the precipitation that was actually received in the study area. The decline in Japanese brome dominance by 2003 was associated with an increase in bindweed dominance. This replacement in species dominance was not observed in the EDYS simulations because Japanese brome was not as affected in the simulations as it was in the field.

At the knapweed site, spotted knapweed dominated the plant community at the beginning of the study. However, as it occurred in the brome site with Japanese brome, the production of this species declined drastically four years later. This decline and the replacement of western wheatgrass as the dominant species was well simulated by the EDYS model. In the knapweed site, generally the EDYS simulations of biomass production did not differ statistically from the field sampling estimations.

At the brome site long-term simulations, Japanese brome and bindweed had negligible biomass by Year 50, while western wheatgrass became the dominant species. At the knapweed site, the population of spotted knapweed was lost by Year 10 and western wheatgrass, twistspine prickly pear, and soapweed became the dominant species. The treatments applied to the study plots had little effect in the long-term simulations. The long-term simulated replacement of weedy invasive species by native perennials, corresponds well to results obtained in long-term studies. In these studies, disturbances seem to favor the dominance of weeds, which are efficient at acquiring water and nutrients. Weeds, however, cannot successfully compete under limitation of resources, which typically occurs as disturbance is eliminated. The EDYS model simulated well these vegetation changes through time and showed to be a valuable tool to forecast the performance of the plant community under different management scenarios.

When grazing was included in the model, no substantial impacts on vegetation total aboveground biomass were seen. Species composition was different at the end of the 50-year simulation. Twistspine pricklypear disappeared from the plots whereas in ungrazed plots it was a major species. Western wheatgrass biomass increased with all levels of grazing and, at the end of 50 years, it was the dominant species. Most other grasses and forbs were gone by the end of the simulation.

When impacts of an M-1 Abrams tank passing through the plots in Year 5 were included in the model, there was no long-term change seen in vegetation biomass and species composition. When impacts of an M-1 Abrams tank or a HMMWV passing through the plots every five years were included in the model, total aboveground biomass was much lower at Year 50 than in undisturbed plots. Species composition was also negatively affected. Biomass of twistspine pricklypear, soapweed, and western wheatgrass, the major species in undisturbed plots, decreased substantially. No species increased and most other grasses and forbs had disappeared by the end of the simulation.

Spotted knapweed and Japanese brome declined in their respective communities and showed great susceptibility to drought conditions. Spotted knapweed was eliminated from the community in a period of 10 years, while Japanese brome survived with very low production until the Year 50. The faster elimination of spotted knapweed may indicate higher susceptibility to drought than Japanese brome. The effect of biological control agents was not clearly expressed, perhaps because it was masked by the overriding influence of the drought. However, the possibility of using biological agents remains as an alternative in controlling knapweed, in contrast to controlling Japanese brome. Although weeds can be eliminated by competition with native perennials under conditions of low resource availability, altered disturbed regimes can easily occur favoring the weed populations.

Ecosystem modeling is a valuable tool to forecast the effects of environmental management. The ecological systems are complex and require comprehensive ecological models that provide realistic scenarios. The EDYS model is a powerful tool in environmental management. The accuracy in EDYS, as in other models, will be greatly enhanced by having reliable data that reflect the actual conditions of the field.

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APPENDIX 1

Soil Series

Neville Fine Sandy Loam

Layer	Layer Name	Depth (mm)	Wilting Point	Field Capacity	Saturation	Organic Matter (g/m^2)	Total N (g/m^2)
1	A	25	25	641.25	51.81	0.518	0.458
2	A	25	50	534.38	43.18	0.432	0.458
3	A	50	100	926.25	74.84	0.748	0.458
4	AC	75	175	1175.63	94.99	0.950	0.444
5	AC	75	250	961.88	77.72	0.777	0.444
6	C	125	375	1325.00	107.06	1.071	0.465
7	C	125	500	1159.38	93.68	0.937	0.465
8	C	125	625	993.75	80.30	0.803	0.465
9	C	125	750	828.13	66.91	0.669	0.465
10	C	175	925	927.50	74.94	0.749	0.499
11	C	175	1100	695.63	56.21	0.562	0.499
12	C	200	1300	530.00	42.82	0.428	0.499
13	C	200	1500	265.00	21.41	0.214	0.499
		1500				**8.858**	**6.118**

APPENDIX 2

Parameterization Matrices for the Fort Carson, Colorado EDYS Application

01. ALLOCATION (Mature)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.15	0.10	0.10	0.45	0.20	0.00
Soapweed	0.15	0.10	0.30	0.20	0.25	0.00
Crested wheatgrass	0.25	0.20	0.10	0.10	0.35	0.00
Western wheatgrass	0.26	0.39	0.12	0.08	0.15	0.00
Purple threeawn	0.09	0.33	0.10	0.15	0.33	0.00
Sideoats grama	0.25	0.25	0.10	0.10	0.30	0.00
Blue grama	0.19	0.30	0.14	0.13	0.14	0.00
Kentucky bluegrass	0.26	0.39	0.12	0.08	0.15	0.00
Little bluestem	0.22	0.33	0.10	0.16	0.19	0.00
Sacaton	0.19	0.28	0.17	0.21	0.15	0.00
Sand dropseed	0.15	0.40	0.15	0.16	0.12	0.00
Green needlegrass	0.26	0.39	0.12	0.08	0.15	0.00
Ragweed	0.27	0.22	0.18	0.23	0.10	0.00
Spotted knapweed	0.09	0.09	0.20	0.40	0.22	0.00
Canada thistle	0.26	0.39	0.12	0.08	0.15	0.00
Bindweed	0.12	0.17	0.15	0.28	0.28	0.00
Scarlet beeblossum	0.41	0.08	0.29	0.14	0.08	0.00
Golden aster	0.42	0.08	0.07	0.40	0.03	0.00
Hoarhound	0.30	0.30	0.13	0.07	0.20	0.00
Alfalfa	0.39	0.16	0.07	0.25	0.13	0.00
Orange globemallow	0.14	0.10	0.25	0.25	0.26	0.00
Mignonette	0.37	0.16	0.08	0.26	0.13	0.00
Wavyleaf thistle	0.26	0.39	0.12	0.08	0.15	0.00
Sweetclover	0.37	0.16	0.08	0.26	0.13	0.00
Japanese brome	0.05	0.20	0.10	0.15	0.50	0.00
Lambsquarters	0.12	0.13	0.10	0.35	0.30	0.00
Sunflower	0.09	0.09	0.20	0.40	0.22	0.00
Bladderpod	0.27	0.07	0.09	0.38	0.19	0.00
Russian thistle	0.14	0.05	0.12	0.46	0.23	0.00
Tansymustard	0.09	0.09	0.20	0.40	0.22	0.00

An EDYS application requires both an initial spatial representation of the plant communities across the simulated landscape and initial biomass values for each of the plant species in each of the plant communities. The initial biomass values are provided in Matrix 26.

The biomass values from Matrix 26 specify how much aboveground biomass is to be entered for each species. However, EDYS also requires a plant-part allocation (distribution) of this biomass (i.e., how much of the initial biomass is leaves, how much is stems, etc.). Matrix 01 provides this initial allocation of the biomass into plant parts.

The first step in determining the allocation values for each species is to determine the root:shoot ratios. These are taken from the literature for each species or, if data are lacking for the species, the most-similar species. Literature root:shoot values are of two types: 1) ratios for mature plants and 2) ratios for plants less than one-year old. The two ratios may be very different for the same species, especially for herbaceous perennials. For example, mature blue grama plants have root:shoot ratios on the order of 2.8, compared to a ratio for annual production of 0.25. The reason for the difference is that most of the aboveground biomass in herbaceous perennials is annual, i.e., it dies at the end of each growing season. In contrast, much of the belowground biomass is perennial. Therefore, over time, the proportional amount of roots increases. Cumulative ratios are used in Matrix 01. Ratios for annual production are used in Matrix 02. Sources of root:shoot ratios used in the Fort Hood application are presented in Appendix Table 1.

The root:shoot ratio is used to determine how much root biomass should be added to the initial shoot biomass provided by Matrix 26, to determine total initial biomass for each species. Total initial root biomass is then allocated between coarse and fine roots (Appendix Table 2).

Initial aboveground biomass is allocated into trunk (crown for grasses), stems, leaves, and seeds (flowers + seeds). The biomass values resulting from the application of Matrix 01 are only initial values used to begin a simulation. As the simulation progresses, these biomass values change on a daily basis, in response to the dynamics of growth, senescence, herbivory, fire, training, etc.

02. ALLOCATION (Current)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.10	0.30	0.10	0.49	0.01	0.00
Soapweed	0.17	0.52	0.15	0.01	0.16	0.00
Crested wheatgrass	0.09	0.09	0.20	0.40	0.22	0.00
Western wheatgrass	0.06	0.24	0.20	0.25	0.25	0.00
Purple threeawn	0.08	0.34	0.10	0.15	0.33	0.00
Sideoats grama	0.09	0.27	0.17	0.05	0.42	0.00
Blue grama	0.07	0.18	0.10	0.25	0.40	0.00
Kentucky bluegrass	0.04	0.31	0.18	0.15	0.32	0.00
Little bluestem	0.04	0.16	0.20	0.30	0.30	0.00
Sacaton	0.05	0.20	0.26	0.32	0.17	0.00
Sand dropseed	0.07	0.23	0.10	0.25	0.35	0.00
Green needlegrass	0.15	0.25	0.15	0.10	0.35	0.00
Ragweed	0.06	0.24	0.08	0.21	0.41	0.00
Spotted knapweed	0.12	0.22	0.08	0.18	0.40	0.00
Canada thistle	0.08	0.13	0.25	0.10	0.44	0.00
Bindweed	0.12	0.17	0.15	0.28	0.28	0.00
Scarlet beeblossum	0.06	0.24	0.20	0.25	0.25	0.00
Golden aster	0.08	0.33	0.05	0.14	0.40	0.00
Hoarhound	0.24	0.36	0.10	0.05	0.25	0.00
Alfalfa	0.16	0.07	0.12	0.42	0.23	0.00
Orange globemallow	0.20	0.23	0.15	0.15	0.27	0.00
Mignonette	0.16	0.07	0.14	0.42	0.21	0.00
Wavyleaf thistle	0.08	0.13	0.25	0.10	0.44	0.00
Sweetclover	0.16	0.07	0.14	0.42	0.21	0.00
Japanese brome	0.10	0.30	0.15	0.15	0.30	0.00
Lambsquarters	0.12	0.13	0.10	0.35	0.30	0.00
Sunflower	0.09	0.09	0.20	0.40	0.22	0.00
Bladderpod	0.27	0.07	0.09	0.38	0.19	0.00
Russian thistle	0.14	0.05	0.12	0.46	0.23	0.00
Tansymustard	0.09	0.09	0.20	0.40	0.22	0.00

*See matrix 02a for values for Japanese brome.

This matrix provides the allocation values for monthly production. For each gram of dry matter biomass produced by a plant species, a certain portion goes to coarse roots, a portion to fine roots, a portion to trunk, etc.

02a. ALLOCATION (Current) – *Bromus japonicus*

Species	Month	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Cheatgrass	Jan	0.10	0.30	0.15	0.15	0.30	0.00
Cheatgrass	Feb	0.10	0.30	0.12	0.13	0.35	0.00
Cheatgrass	Mar	0.08	0.30	0.15	0.15	0.32	0.00
Cheatgrass	Apr	0.08	0.25	0.15	0.15	0.37	0.00
Cheatgrass	May	0.08	0.20	0.15	0.17	0.40	0.00
Cheatgrass	June	0.08	0.20	0.15	0.17	0.40	0.00
Cheatgrass	July	0.08	0.20	0.15	0.17	0.40	0.00
Cheatgrass	Aug	0.00	0.00	0.00	0.00	0.00	0.00
Cheatgrass	Sep	0.00	0.00	0.00	0.00	0.00	0.00
Cheatgrass	Oct	0.05	0.45	0.10	0.10	0.30	0.00
Cheatgrass	Nov	0.05	0.45	0.10	0.10	0.30	0.00
Cheatgrass	Dec	0.10	0.30	0.15	0.15	0.30	0.00

03. GREEN-OUT ALLOCATION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.00	0.30	0.10	0.60	0.00	0.00
Soapweed	0.00	0.52	0.13	0.01	0.34	0.00
Crested wheatgrass	0.00	0.09	0.00	0.50	0.41	0.00
Western wheatgrass	0.00	0.20	0.00	0.20	0.60	0.00
Purple threeawn	0.00	0.30	0.00	0.20	0.50	0.00
Sideoats grama	0.00	0.25	0.00	0.02	0.73	0.00
Blue grama	0.00	0.18	0.00	0.20	0.62	0.00
Kentucky bluegrass	0.00	0.30	0.00	0.20	0.50	0.00
Little bluestem	0.00	0.15	0.00	0.40	0.45	0.00
Sacaton	0.00	0.20	0.00	0.30	0.50	0.00
Sand dropseed	0.00	0.23	0.00	0.30	0.47	0.00
Green needlegrass	0.00	0.00	0.00	0.20	0.80	0.00
Ragweed	0.00	0.24	0.08	0.20	0.48	0.00
Spotted knapweed	0.00	0.09	0.00	0.50	0.41	0.00
Canada thistle	0.00	0.10	0.00	0.20	0.70	0.00
Bindweed	0.00	0.17	0.13	0.25	0.45	0.00
Scarlet beeblossum	0.00	0.20	0.10	0.35	0.35	0.00
Golden aster	0.00	0.30	0.00	0.22	0.48	0.00
Hoarhound	0.00	0.35	0.00	0.10	0.55	0.00
Alfalfa	0.00	0.05	0.00	0.57	0.38	0.00
Orange globemallow	0.00	0.23	0.13	0.15	0.49	0.00
Mignonette	0.00	0.06	0.00	0.63	0.31	0.00
Wavyleaf thistle	0.00	0.10	0.00	0.20	0.70	0.00
Sweetclover	0.00	0.06	0.00	0.63	0.31	0.00
Japanese brome	0.00	0.20	0.00	0.20	0.60	0.00
Lambsquarters	0.00	0.10	0.10	0.30	0.50	0.00
Sunflower	0.00	0.09	0.00	0.50	0.41	0.00
Bladderpod	0.00	0.05	0.00	0.57	0.38	0.00
Russian thistle	0.00	0.05	0.00	0.59	0.36	0.00
Tansymustard	0.00	0.09	0.00	0.50	0.41	0.00

This matrix provides the allocation values for production in a month when either dormancy is broken (e.g., spring green-up) or regrowth is triggered following a major defoliation event (e.g., heavy grazing, trampling, fire). The primary difference between this matrix and the current-growth allocation matrix (02) is that in green-out there is no allocation to coarse roots and to grass trunks. These are the primary storage regions for non-structural carbohydrates, which are used initially to produce regrowth (Stoddart et al. 1975:107, Garza et al. 1994).

04. SEED MONTH ALLOCATION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.00	0.30	0.05	0.25	0.01	0.39
Soapweed	0.10	0.40	0.01	0.01	0.10	0.38
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	1.00
Western wheatgrass	0.00	0.24	0.00	0.25	0.12	0.39
Purple threeawn	0.00	0.34	0.00	0.15	0.17	0.34
Sideoats grama	0.00	0.27	0.00	0.05	0.21	0.47
Blue grama	0.00	0.18	0.00	0.25	0.20	0.37
Kentucky bluegrass	0.00	0.31	0.00	0.15	0.16	0.38
Little bluestem	0.00	0.16	0.00	0.27	0.27	0.30
Sacaton	0.00	0.20	0.00	0.32	0.09	0.39
Sand dropseed	0.00	0.23	0.00	0.25	0.18	0.34
Green needlegrass	0.02	0.03	0.03	0.02	0.21	0.70
Ragweed	0.06	0.24	0.04	0.10	0.37	0.19
Spotted knapweed	0.00	0.00	0.00	0.00	0.00	1.00
Canada thistle	0.00	0.13	0.00	0.10	0.22	0.55
Bindweed	0.00	0.17	0.00	0.28	0.14	0.41
Scarlet beeblossum	0.08	0.22	0.10	0.12	0.22	0.26
Golden aster	0.08	0.33	0.02	0.07	0.36	0.14
Hoarhound	0.00	0.36	0.00	0.05	0.12	0.47
Alfalfa	0.00	0.07	0.00	0.42	0.12	0.39
Orange globemallow	0.00	0.23	0.00	0.15	0.13	0.49
Mignonette	0.00	0.07	0.00	0.42	0.11	0.40
Wavyleaf thistle	0.00	0.13	0.00	0.10	0.22	0.55
Sweetclover	0.00	0.07	0.00	0.42	0.11	0.40
Japanese brome	0.00	0.00	0.00	0.00	0.00	1.00
Lambsquarters	0.00	0.00	0.00	0.00	0.00	1.00
Sunflower	0.00	0.00	0.00	0.00	0.00	1.00
Bladderpod	0.00	0.00	0.00	0.00	0.10	0.90
Russian thistle	0.00	0.00	0.00	0.00	0.10	0.90
Tansymustard	0.00	0.00	0.00	0.00	0.00	1.00

This matrix provides the allocation values for production in months in which flowering and seed production occurs. For woody plants, 50% of trunk and stem growth and 10% of leaf growth is diverted to seeds. For herbaceous perennials, 100% of coarse root and trunk growth and 50% of leaf growth is diverted to seeds. For annuals, all growth is diverted to seeds. Some exceptions are made for species that are typically heavy seed producers or for species that are poor seed producers.

05. PLANT N CONCENTRATION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Twistspine pricklypear	0.0212	0.0210	0.0220	0.0254	0.0260	0.0300	0.0210	0.0239	0.0210	0.0283	0.0300
Soapweed	0.0120	0.0130	0.0150	0.0095	0.0180	0.0190	0.0090	0.0095	0.0125	0.0190	0.0190
Crested wheatgrass	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Western wheatgrass	0.0070	0.0070	0.0120	0.0120	0.0130	0.0200	0.0100	0.0100	0.0070	0.0135	0.0200
Purple threeawn	0.0078	0.0080	0.0079	0.0080	0.0082	0.0200	0.0070	0.0070	0.0080	0.0085	0.0200
Sideoats grama	0.0101	0.0110	0.0120	0.0134	0.0140	0.0200	0.0125	0.0135	0.0110	0.0183	0.0200
Blue grama	0.0100	0.0102	0.0100	0.0102	0.0125	0.0200	0.0085	0.0085	0.0102	0.0130	0.0200
Kentucky bluegrass	0.0100	0.0105	0.0110	0.0110	0.0125	0.0200	0.0095	0.0100	0.0125	0.0130	0.0200
Little bluestem	0.0100	0.0102	0.0100	0.0100	0.0125	0.0200	0.0080	0.0071	0.0105	0.0130	0.0200
Sacaton	0.0070	0.0080	0.0110	0.0120	0.0130	0.0200	0.0090	0.0100	0.0080	0.0140	0.0200
Sand dropseed	0.0090	0.0095	0.0100	0.0110	0.0110	0.0200	0.0095	0.0100	0.0100	0.0110	0.0200
Green needlegrass	0.0160	0.0182	0.0160	0.0160	0.0182	0.0218	0.0110	0.0110	0.0182	0.0182	0.0218
Ragweed	0.0085	0.0090	0.0085	0.0090	0.0180	0.0185	0.0065	0.0135	0.0095	0.0190	0.0185
Spotted knapweed	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Canada thistle	0.0130	0.0135	0.0110	0.0110	0.0130	0.0200	0.0105	0.0115	0.0140	0.0140	0.0200
Bindweed	0.0220	0.0222	0.0221	0.0222	0.0227	0.0198	0.0178	0.0178	0.0225	0.0230	0.0198
Scarlet beeblossum	0.0110	0.0120	0.0160	0.0090	0.0175	0.0330	0.0080	0.0087	0.0120	0.0200	0.0330
Golden aster	0.0140	0.0150	0.0150	0.0164	0.0180	0.0186	0.0144	0.0150	0.0180	0.0200	0.0186
Hoarhound	0.0146	0.0148	0.0146	0.0148	0.0150	0.0210	0.0128	0.0132	0.0186	0.0188	0.0210
Alfalfa	0.0240	0.0250	0.0220	0.0240	0.0250	0.0457	0.0149	0.0155	0.0317	0.0317	0.0457
Orange globemallow	0.0146	0.0148	0.0146	0.0148	0.0150	0.0200	0.0128	0.0132	0.0186	0.0188	0.0200
Mignonette	0.0240	0.0250	0.0220	0.0240	0.0250	0.0457	0.0149	0.0155	0.0317	0.0317	0.0457
Wavyleaf thistle	0.0130	0.0135	0.0110	0.0110	0.0130	0.0200	0.0105	0.0115	0.0140	0.0140	0.0200
Sweetclover	0.0240	0.0250	0.0220	0.0240	0.0250	0.0457	0.0149	0.0155	0.0317	0.0317	0.0457
Japanese brome	0.0090	0.0090	0.0104	0.0106	0.0110	0.0173	0.0073	0.0073	0.0090	0.0142	0.0173
Lambsquarters	0.0150	0.0160	0.0150	0.0162	0.0170	0.0243	0.0097	0.0105	0.0251	0.0251	0.0243
Sunflower	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Bladderpod	0.0080	0.0090	0.0090	0.0150	0.0180	0.0300	0.0140	0.0170	0.0070	0.0100	0.0300
Russian thistle	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Tansymustard	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214

This matrix provides initial values for nitrogen (N) concentrations in plant tissues. The value in a particular tissue may vary from these values at any point in a simulation for either of two reasons. First, values may exceed these values because of "luxury consumption", i.e., the amount of N contained in the water absorbed by the plant may be sufficient to exceed these matrix values. Secondly, values may be less than the matrix values in some tissues because of internal transport of N from one tissue type to another during periods of green-out or rapid growth. The lower boundary for these concentrations are the maintenance levels, i.e., the concentration at which that particular tissue can remain alive but not growing. Maintenance levels are provided in Matrix 06 and are arbitrarily set at 75% of the Matrix 05 levels for non-legumes and 25% for legumes.

Matrix 05 values are based on tissue N concentrations of composite aboveground tissue for the species, or most-similar species. Most of these values were taken from a large set of unpublished values from tissue samples we have analyzed in connection with a number of research projects. A limited amount of these data have been published (McLendon and Redente 1992, Redente et al. 1992, McLendon and Redente 1994, Paschke et al. 2000). A more complete set of the data are currently being prepared for publication. Additional values were taken from the literature.

When available, values for separate tissue types were used. Most often, tissue type concentrations were estimated from averages found in the literature (Gigon and Rorison 1972, Barth and Klemmedson 1982, Gay et al. 1982, Nicholas and McGinnes 1982, Risser and Parton 1982, Vogt et al. 1982, Heil and Diemont 1983, Stout et al. 1983, Uhl and Jordan 1984, McClaugherty et al. 1985, Nadelhoffer et al. 1985, Sears et al. 1986, Agren and Bosatta 1987, O'Connell 1988, McNeill and Wood 1990, Tilman and Wedin 1991).

06. MAINTENANCE LEVELS

Species	75%	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Twistspine pricklypear	0.9000	0.0212	0.0210	0.0220	0.0254	0.0260	0.0300	0.0210	0.0239	0.0210	0.0283	0.0300
Soapweed	0.7500	0.0120	0.0130	0.0150	0.0095	0.0180	0.0190	0.0090	0.0095	0.0125	0.0190	0.0190
Crested wheatgrass	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Western wheatgrass	0.7500	0.0070	0.0070	0.0120	0.0120	0.0130	0.0200	0.0100	0.0100	0.0070	0.0135	0.0200
Purple threeawn	0.9000	0.0078	0.0080	0.0079	0.0080	0.0082	0.0200	0.0070	0.0070	0.0080	0.0085	0.0200
Sideoats grama	0.7500	0.0101	0.0110	0.0120	0.0134	0.0140	0.0200	0.0125	0.0135	0.0110	0.0183	0.0200
Blue grama	0.7500	0.0100	0.0102	0.0100	0.0102	0.0125	0.0200	0.0085	0.0085	0.0102	0.0130	0.0200
Kentucky bluegrass	0.7500	0.0100	0.0105	0.0110	0.0110	0.0125	0.0200	0.0095	0.0100	0.0125	0.0130	0.0200
Little bluestem	0.7500	0.0100	0.0102	0.0100	0.0100	0.0125	0.0200	0.0080	0.0071	0.0105	0.0130	0.0200
Sacaton	0.7500	0.0070	0.0080	0.0110	0.0120	0.0130	0.0200	0.0090	0.0100	0.0080	0.0140	0.0200
Sand dropseed	0.9000	0.0090	0.0095	0.0100	0.0110	0.0110	0.0200	0.0095	0.0100	0.0100	0.0110	0.0200
Green needlegrass	0.0160	0.0160	0.0182	0.0160	0.0160	0.0182	0.0218	0.0110	0.0110	0.0182	0.0182	0.0218
Ragweed	0.7500	0.0085	0.0090	0.0085	0.0090	0.0180	0.0185	0.0065	0.0135	0.0095	0.0190	0.0185
Spotted knapweed	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Canada thistle	0.7500	0.0130	0.0135	0.0110	0.0110	0.0130	0.0200	0.0105	0.0115	0.0140	0.0140	0.0200
Bindweed	0.7500	0.0220	0.0222	0.0221	0.0222	0.0227	0.0198	0.0178	0.0178	0.0225	0.0230	0.0198
Scarlet beeblossum	0.7500	0.0110	0.0120	0.0160	0.0090	0.0175	0.0330	0.0080	0.0087	0.0120	0.0200	0.0330
Golden aster	0.7500	0.0140	0.0150	0.0150	0.0164	0.0180	0.0186	0.0144	0.0150	0.0180	0.0200	0.0186
Hoarhound	0.7500	0.0146	0.0148	0.0146	0.0148	0.0150	0.0210	0.0128	0.0132	0.0186	0.0188	0.0210
Alfalfa	0.2500	0.0240	0.0250	0.0220	0.0240	0.0250	0.0457	0.0149	0.0155	0.0317	0.0317	0.0457
Orange globemallow	0.7500	0.0146	0.0148	0.0146	0.0148	0.0150	0.0200	0.0128	0.0132	0.0186	0.0188	0.0200
Mignonette	0.2500	0.0240	0.0250	0.0220	0.0240	0.0250	0.0457	0.0149	0.0155	0.0317	0.0317	0.0457
Wavyleaf thistle	0.7500	0.0130	0.0135	0.0110	0.0110	0.0130	0.0200	0.0105	0.0115	0.0140	0.0140	0.0200
Sweetclover	0.2500	0.0240	0.0250	0.0220	0.0240	0.0250	0.0457	0.0149	0.0155	0.0317	0.0317	0.0457
Japanese brome	0.7500	0.0090	0.0090	0.0104	0.0106	0.0110	0.0173	0.0073	0.0073	0.0090	0.0142	0.0173
Lambsquarters	0.7500	0.0150	0.0160	0.0150	0.0162	0.0170	0.0243	0.0097	0.0105	0.0251	0.0251	0.0243
Sunflower	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Bladderpod	0.7500	0.0080	0.0090	0.0090	0.0150	0.0180	0.0300	0.0140	0.0170	0.0070	0.0100	0.0300
Russian thistle	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214
Tansymustard	0.7500	0.0175	0.0180	0.0175	0.0180	0.0182	0.0214	0.0090	0.0094	0.0246	0.0240	0.0214

07. NITROGEN RESORPTION

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.10	0.05	0.00	0.05	0.10	0.00
Soapweed	0.10	0.05	0.00	0.10	0.15	0.00
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00
Western wheatgrass	0.10	0.05	0.05	0.05	0.10	0.00
Purple threeawn	0.00	0.00	0.00	0.00	0.00	0.00
Sideoats grama	0.10	0.05	0.00	0.05	0.10	0.00
Blue grama	0.10	0.05	0.00	0.05	0.10	0.00
Kentucky bluegrass	0.05	0.05	0.00	0.05	0.10	0.00
Little bluestem	0.10	0.05	0.00	0.05	0.10	0.00
Sacaton	0.10	0.05	0.05	0.05	0.05	0.00
Sand dropseed	0.10	0.05	0.00	0.05	0.10	0.00
Green needlegrass	0.31	0.31	0.31	0.31	0.31	0.30
Ragweed	0.05	0.03	0.00	0.05	0.10	0.00
Spotted knapweed	0.00	0.00	0.00	0.00	0.00	0.00
Canada thistle	0.10	0.05	0.05	0.05	0.10	0.00
Bindweed	0.10	0.05	0.00	0.10	0.20	0.00
Scarlet beeblossum	0.10	0.05	0.00	0.05	0.10	0.00
Golden aster	0.10	0.05	0.00	0.05	0.10	0.00
Hoarhound	0.05	0.03	0.00	0.05	0.05	0.00
Alfalfa	0.05	0.03	0.00	0.05	0.10	0.00
Orange globemallow	0.05	0.03	0.00	0.05	0.10	0.00
Mignonette	0.05	0.03	0.00	0.05	0.10	0.00
Wavyleaf thistle	0.10	0.05	0.05	0.05	0.10	0.00
Sweetclover	0.05	0.03	0.00	0.05	0.10	0.00
Japanese brome	0.00	0.00	0.00	0.00	0.00	0.00
Lambsquarters	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00
Bladderpod	0.00	0.00	0.00	0.00	0.00	0.00
Russian thistle	0.00	0.00	0.00	0.00	0.00	0.00
Tansymustard	0.00	0.00	0.00	0.00	0.00	0.00

Many species of plants resorb a portion of nitrogen contained in tissue during senescence of the tissue and prior to death of that tissue. This is especially common in tree leaves. This matrix provides the maximum amount of nitrogen within each tissue type that can be resorbed prior to tissue loss. The values are general estimates based on differences between nitrogen contents in green tissues and nitrogen contents in dead tissues.

08. ROOT ARCHITECTURE

Species	Percent of Soil Profile Depth												Max Root Depth (cm)
	0-1	1-5	5-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	
Twistspine pricklypear	0.13	0.37	0.30	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	400
Soapweed	0.14	0.51	0.23	0.07	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	400
Crested wheatgrass	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	1400
Western wheatgrass	0.10	0.20	0.25	0.12	0.07	0.06	0.05	0.05	0.04	0.03	0.02	0.01	3600
Purple threeawn	0.20	0.20	0.18	0.14	0.10	0.06	0.04	0.03	0.02	0.01	0.01	0.01	1400
Sideoats grama	0.06	0.15	0.15	0.18	0.17	0.12	0.08	0.05	0.01	0.01	0.01	0.01	1800
Blue grama	0.13	0.37	0.30	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	3960
Kentucky bluegrass	0.10	0.20	0.25	0.12	0.07	0.06	0.05	0.05	0.04	0.03	0.02	0.01	3600
Little bluestem	0.12	0.35	0.28	0.08	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0.01	2440
Sacaton	0.12	0.24	0.14	0.21	0.11	0.06	0.04	0.03	0.02	0.01	0.01	0.01	2130
Sand dropseed	0.08	0.20	0.14	0.20	0.20	0.06	0.04	0.03	0.02	0.01	0.01	0.01	2130
Green needlegrass	0.08	0.15	0.20	0.20	0.20	0.08	0.08	0.00	0.00	0.00	0.00	0.00	3600
Ragweed	0.03	0.90	0.11	0.18	0.15	0.12	0.10	0.08	0.06	0.04	0.03	0.01	2400
Spotted knapweed	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Canada thistle	0.33	0.15	0.11	0.09	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	3600
Bindweed	0.18	0.17	0.40	0.12	0.06	0.04	0.03	0.00	0.00	0.00	0.00	0.00	3600
Scarlet beeblossum	0.02	0.06	0.07	0.16	0.15	0.11	0.08	0.07	0.05	0.05	0.03	0.02	2900
Golden aster	0.03	0.13	0.16	0.18	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.02	2000
Hoarhound	0.08	0.16	0.16	0.24	0.12	0.08	0.06	0.04	0.02	0.02	0.01	0.01	1560
Alfalfa	0.02	0.04	0.09	0.10	0.10	0.12	0.12	0.12	0.11	0.10	0.06	0.02	9000
Orange globemallow	0.06	0.14	0.16	0.30	0.16	0.06	0.04	0.03	0.02	0.01	0.01	0.01	4100
Mignonette	0.02	0.04	0.09	0.10	0.10	0.12	0.12	0.12	0.11	0.10	0.06	0.02	1400
Wavyleaf thistle	0.33	0.15	0.11	0.09	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	3600
Sweetclover	0.02	0.04	0.09	0.10	0.10	0.12	0.12	0.12	0.11	0.10	0.06	0.02	1400
Japanese brome	0.28	0.35	0.11	0.08	0.06	0.03	0.02	0.02	0.02	0.02	0.01	0.01	1500
Lambsquarters	0.09	0.34	0.25	0.15	0.11	0.04	0.02	0.00	0.00	0.00	0.00	0.00	3600
Sunflower	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670
Bladderpod	0.08	0.22	0.06	0.09	0.12	0.16	0.10	0.07	0.02	0.03	0.03	0.02	3000
Russian thistle	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	2000
Tansymustard	0.06	0.16	0.18	0.24	0.12	0.08	0.05	0.04	0.03	0.02	0.01	0.01	670

This matrix provides 1) the percentage of the total root biomass of each species that occurs at given depths (%) of soil profiles and 2) the maximum reported rooting depth for each species. We have collected a significant amount of root architecture data, both from the published literature and from our own studies. For each species, we compare the amount of roots reported by depth among all studies for which we have data available for that species. An example for little bluestem is presented in Appendix Table 3. These data are then used to calculate an average root biomass by depth values. We have found that root biomass by depth percentages are relatively consistent across soil profiles for a given species, even where the depths of the soil profiles vary significantly.

The root percentages (Matrix 08) are multiplied by the estimated initial root biomass value for that species (Matrix 01) to arrive at an initial root biomass within each layer for each soil profile in the landscape. These are initial values only. As the EDYS simulation progresses, root architecture changes because of root growth and the location (depth) of belowground resources. Daily root production, based in part on the appropriate allocation matrix (01-04), is added to the existing root biomass proportional to the amount of root biomass in each soil layer that supplied water to the plant in that particular day. This is based on two related concepts: 1) more root occurs in moist soil than in dry soil and 2) root growth in a soil layer is largely independent of soil moisture levels in other layers (Kramer 1969:136, Brown and Scott 1984:125, Huck 1984:59).

Maximum rooting depth sets the maximum depth to which a particular species can root. This is the maximum value found for that species, or the most-similar species, in the literature. We assume this limit to be primarily genetically determined, since we used the maximum reported depth. If we used the average maximum rooting depth, we would assume that the depth would be also be strongly influenced by environmental factors.

Sources of root architecture data are presented in Appendix Table 4. Sources of maximum rooting depth data are presented in Appendix Table 5.

09. ROOT UPTAKE AND COMPETITIVE EFFICIENCY

Species	Uptake Capacity	Biomass Adjustment
Twistspine pricklypear	0.10	0.50
Soapweed	0.10	0.80
Crested wheatgrass	0.10	0.95
Western wheatgrass	0.10	0.90
Purple threeawn	0.10	1.00
Sideoats grama	0.10	1.00
Blue grama	0.10	1.00
Kentucky bluegrass	0.10	1.00
Little bluestem	0.10	0.95
Sacaton	0.10	1.00
Sand dropseed	0.10	1.00
Green needlegrass	0.20	0.50
Ragweed	0.10	0.80
Spotted knapweed	0.10	0.95
Canada thistle	0.10	0.90
Bindweed	0.10	1.00
Scarlet beeblossum	0.10	0.75
Golden aster	0.10	0.80
Hoarhound	0.10	0.95
Alfalfa	0.10	0.95
Orange globemallow	0.10	1.00
Mignonette	0.10	0.95
Wavyleaf thistle	0.10	0.90
Sweetclover	0.10	0.95
Japanese brome	0.10	1.00
Lambsquarters	0.10	0.95
Sunflower	0.10	0.95
Bladderpod	0.10	1.00
Russian thistle	0.10	0.95
Tansymustard	0.10	0.95

Uptake capacity is the maximum amount of monthly water demand that can be supplied by the root system in one day. This was estimated to be 10%.

Competitive efficiency is a measure of the relative efficiency of roots in water uptake. The fibrous root system of most short-grasses is used as the standard, and is assigned a competitive efficiency value of 1.0. Larger grasses, such as little bluestem, are assumed to have larger roots than shortgrasses. The larger roots of midgrasses are assumed to have a slightly lower efficiency for water uptake than the smaller roots of the shortgrasses. The larger roots of trees are assumed to be significantly less efficient, on a per gram basis, of water uptake than the smaller, fibrous roots of grasses. These relationships are based on the concept that water intake by roots is partly dependent on surface area of the roots.

10. PHYSIOLOGICAL RESPONSE MONTHS

Species	Green-out	Seed Sprout	Seed Set	Dormancy
Twistspine pricklypear	3	6,8	7,8	12
Soapweed	4	4,7	6,7	2
Crested wheatgrass	3	3,8	5,8	10
Western wheatgrass	3	5,6	6,8	10
Purple threeawn	2	3,8	4,9	12
Sideoats grama	3	3,8	6,9	11
Blue grama	3	3,8	6,10	11
Kentucky bluegrass	3	4,8	5,9	11
Little bluestem	4	3,8	8,10	11
Sacaton	3	3,9	5,9	11
Sand dropseed	3	3,9	6,9	11
Green needlegrass	5	6,7	8,9	10
Ragweed	2	1,10	3,10	11
Spotted knapweed	4	3,8	5,8	10
Canada thistle	3	4,9	5,9	10
Bindweed	3	3,9	4,9	10
Scarlet beeblossum	3	4,8	4,8	10
Golden aster	3	3,9	5,9	10
Hoarhound	2	2,6	3,5	7
Alfalfa	3	3,9	5,9	10
Orange globemallow	3	3,9	5,9	10
Mignonette	3	3,9	4,8	11
Wavyleaf thistle	3	4,9	5,9	10
Sweetclover	3	3,9	4,8	11
Japanese brome	10	10,4	4,7	7
Lambsquarters	5	5,8	6,8	10
Sunflower	3	3,8	5,8	10
Bladderpod	3	3,8	6,8	11
Russian thistle	3	3,9	6,9	10
Tansymustard	2	3,8	5,8	10

This is the phenology matrix. It provides the data that are used in the model to determine which months various plant functions occur. Data sources were Gould (1975) for most of the grasses and Correll and Johnston (1970) for most of the non-grasses. Green-out and dormancy values were based on personal estimates.

11. BIOMASS CONVERSION CONSTANTS

Species	Dry wt/ Wet wt	Moisture Interception/ g biomass	Basal cover/Trunk biomass
Twistspine pricklypear	0.10	0.00256	30
Soapweed	0.30	0.00850	20
Crested wheatgrass	0.22	0.00820	2
Western wheatgrass	0.35	0.00840	3
Purple threeawn	0.39	0.00700	30
Sideoats grama	0.34	0.00850	2
Blue grama	0.34	0.00860	4
Kentucky bluegrass	0.34	0.00840	2
Little bluestem	0.35	0.00860	3
Sacaton	0.35	0.00860	8
Sand dropseed	0.35	0.00820	40
Green needlegrass	0.10	0.00256	30
Ragweed	0.28	0.00800	10
Spotted knapweed	0.22	0.00820	2
Canada thistle	0.30	0.00900	2
Bindweed	0.35	0.00800	1
Scarlet beeblossum	0.28	0.00850	2
Golden aster	0.32	0.00870	20
Hoarhound	0.30	0.00840	2
Alfalfa	0.25	0.00860	2
Orange globemallow	0.30	0.00820	1
Mignonette	0.25	0.00840	2
Wavyleaf thistle	0.30	0.00900	2
Sweetclover	0.25	0.00840	2
Japanese brome	0.30	0.00820	1
Lambsquarters	0.22	0.00840	2
Sunflower	0.22	0.00820	2
Bladderpod	0.32	0.00880	3
Russian thistle	0.22	0.00800	2
Tansymustard	0.22	0.00820	2

This matrix provides values for 1) conversions between dry weight and wet weight, 2) amount of moisture intercepted by the canopy of each species, and 3) conversions between basal area and trunk biomass. These calculations are required for various calculations used in the simulations.

The dry weight values for herbaceous species were taken from Morrison (1961:556-575), or estimated from values from that source. Moisture interception values were estimated. Basal area to trunk biomass values were estimated from calculations based on unpublished field data collected in McLendon et al. (1999c, 2000b). Values for herbaceous species were estimated.

12. WATER USE FACTORS

Species	Maintenance (mm/g bio/mo)	New biomass maintenance	Water to production	Green-out water use
Twistspine pricklypear	0.0000083	0.05	0.30	0.80
Soapweed	0.0000070	0.03	0.51	0.60
Crested wheatgrass	0.0000150	0.03	0.70	0.78
Western wheatgrass	0.0000150	0.04	0.80	0.65
Purple threeawn	0.0000124	0.04	0.56	0.61
Sideoats grama	0.0000160	0.04	0.80	0.66
Blue grama	0.0000160	0.04	0.78	0.66
Kentucky bluegrass	0.0000190	0.06	1.50	0.66
Little bluestem	0.0000170	0.06	0.70	0.65
Sacaton	0.0000118	0.03	0.65	0.65
Sand dropseed	0.0000160	0.05	0.72	0.65
Green needlegrass	0.0000083	0.05	0.99	0.80
Ragweed	0.0000070	0.03	0.27	0.72
Spotted knapweed	0.0000150	0.03	0.65	0.78
Canada thistle	0.0000220	0.07	0.89	0.70
Bindweed	0.0000200	0.06	0.75	0.65
Scarlet beeblossum	0.0000090	0.04	1.00	0.72
Golden aster	0.0000042	0.04	0.90	0.68
Hoarhound	0.0000220	0.04	0.65	0.70
Alfalfa	0.0000174	0.04	1.40	0.75
Orange globemallow	0.0000180	0.05	0.78	0.70
Mignonette	0.0000250	0.06	0.96	0.75
Wavyleaf thistle	0.0000220	0.07	0.80	0.70
Sweetclover	0.0000250	0.06	1.06	0.75
Japanese brome	0.0000180	0.07	0.45	0.70
Lambsquarters	0.0000170	0.03	0.53	0.78
Sunflower	0.0000150	0.03	0.60	0.78
Bladderpod	0.0000116	0.03	0.58	0.60
Russian thistle	0.0000050	0.03	0.20	0.78
Tansymustard	0.0000150	0.03	0.54	0.78

This matrix provides four sets of numbers that are used by EDYS to calculate water requirements of the plants. Green-out water use is the amount of water used to change from dry weight to wet weight. It is 1.00 - dry weight (Matrix 11). Maintenance is the amount of water required to support 1 g of old-growth biomass for one month. Old-growth biomass is that amount of live biomass that was produced in previous years. New biomass maintenance is the amount of water required to sustain 1 g of new-growth biomass for one month, in months where no new growth takes place. If this amount of water is not available, a proportional amount of new-growth tissue is converted to standing dead biomass (i.e., drought loss). The maintenance water-use values are estimates.

Water to production is the amount of water (kg) required to produce 1 g of new biomass. These values are taken from literature data for water-use efficiencies (Appendix Table 6).

13. GROWTH RATE FACTORS

Species	Max growth rate	Max old biomass drought loss
Twistspine pricklypear	0.10	0.70
Soapweed	0.15	0.10
Crested wheatgrass	3.00	0.40
Western wheatgrass	2.50	0.40
Purple threeawn	3.00	0.70
Sideoats grama	2.20	0.40
Blue grama	2.20	0.40
Kentucky bluegrass	1.60	0.50
Little bluestem	1.50	0.40
Sacaton	2.50	0.30
Sand dropseed	3.10	0.70
Green needlegrass	2.00	0.70
Ragweed	0.25	0.10
Spotted knapweed	2.40	0.40
Canada thistle	2.00	0.60
Bindweed	2.00	0.50
Scarlet beeblossum	0.75	0.25
Golden aster	2.28	0.30
Hoarhound	1.80	0.40
Alfalfa	3.38	0.40
Orange globemallow	2.50	0.40
Mignonette	2.67	0.50
Wavyleaf thistle	2.00	0.60
Sweetclover	2.67	0.50
Japanese brome	2.50	0.40
Lambsquarters	2.20	0.50
Sunflower	2.50	0.40
Bladderpod	2.28	0.40
Russian thistle	3.18	0.40
Tansymustard	2.50	0.40

Maximum growth rate is the estimated increase in aboveground biomass that could occur in one month under ideal conditions. It is a productivity value. A value of 1.00 results in biomass doubling each month. The growth rate value is multiplied by the amount of leaf-equivalent photosynthetically-active biomass (Matrix 15) to determine potential monthly production. For potential monthly production to be achieved, there has to be sufficient water, nutrients, and sunlight available to the species to achieve this production level. If any of these factors are limiting, potential monthly production is reduced proportionally. The amount of production actually achieved is then allocated according to the appropriate allocation matrix (01-04).

The highest productivity rates are assigned to annuals, followed by herbaceous perennials, and then woody species. The rates were estimated, based on experience. Values reported in the literature for similar grass species range from 0.87 to 4.74 (Lissner et al. 1999, Fernandez and Reynolds 2000).

14. MONTHLY MAXIMUM GROWTH RATES

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Twistspine pricklypear	0.00	0.10	0.10	0.30	0.80	1.00	1.00	1.00	0.70	0.20	0.00	0.00
Soapweed	0.00	0.10	0.40	0.60	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.00
Crested wheatgrass	0.00	0.00	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Western wheatgrass	0.00	0.00	0.50	0.90	1.00	1.00	0.80	0.70	0.70	0.50	0.20	0.00
Purple threeawn	0.00	0.10	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.10	0.00
Sideoats grama	0.00	0.10	0.20	0.50	0.80	1.00	1.00	0.90	0.90	0.50	0.00	0.00
Blue grama	0.00	0.00	0.40	0.80	1.00	1.00	1.00	1.00	0.80	0.50	0.10	0.00
Kentucky bluegrass	0.00	0.00	0.50	0.80	1.00	1.00	1.00	1.00	1.00	0.60	0.30	0.00
Little bluestem	0.00	0.00	0.50	0.90	1.00	1.00	1.00	1.00	0.90	0.50	0.20	0.00
Sacaton	0.00	0.10	0.40	1.00	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.00
Sand dropseed	0.00	0.10	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.10	0.00
Green needlegrass	0.00	0.00	0.00	0.60	0.90	1.00	1.00	0.90	0.60	0.00	0.00	0.00
Ragweed	0.00	0.20	0.60	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.20	0.05
Spotted knapweed	0.00	0.00	0.30	0.60	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Canada thistle	0.00	0.00	0.60	0.90	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Bindweed	0.00	0.20	0.30	0.60	1.00	1.00	1.00	1.00	0.70	0.30	0.10	0.00
Scarlet beeblossum	0.00	0.00	0.50	0.90	1.00	1.00	1.00	1.00	0.80	0.50	0.00	0.00
Golden aster	0.00	0.10	0.30	0.80	1.00	1.00	1.00	0.80	0.60	0.30	0.00	0.00
Hoarhound	0.00	0.00	0.40	0.80	1.00	1.00	0.80	0.60	0.40	0.20	0.10	0.00
Alfalfa	0.00	0.20	0.40	0.80	1.00	1.00	1.00	0.80	0.70	0.40	0.20	0.00
Orange globemallow	0.00	0.20	0.50	0.90	1.00	1.00	1.00	0.90	0.80	0.40	0.10	0.00
Mignonette	0.00	0.20	0.50	0.80	1.00	1.00	1.00	0.60	0.50	0.30	0.10	0.00
Wavyleaf thistle	0.00	0.00	0.60	0.90	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Sweetclover	0.00	0.20	0.50	0.80	1.00	1.00	1.00	0.60	0.50	0.30	0.10	0.00
Japanese brome	0.10	0.30	0.50	1.00	1.00	1.00	0.20	0.00	0.00	0.60	0.50	0.25
Lambsquarters	0.00	0.00	0.00	0.20	0.80	1.00	1.00	1.00	0.80	0.60	0.20	0.00
Sunflower	0.00	0.00	0.50	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Bladderpod	0.10	0.30	0.80	1.00	1.00	0.90	0.80	0.70	0.80	0.40	0.20	0.10
Russian thistle	0.00	0.00	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00
Tansymustard	0.00	0.10	0.40	1.00	1.00	1.00	1.00	1.00	0.70	0.30	0.00	0.00

The potential growth rates in Matrix 13 are the estimates for ideal conditions. One limiting factor is temperature. Warm-season species are most productive during the warmer part of the year and cool-season species are more productive during the cool season. Matrix 14 provides a monthly growth curve for each species. The monthly growth rate value for the specific month is multiplied by the potential growth rate (Matrix 13) to determine the potential growth rate for that particular month. This is still a potential growth rate. It may be reduced because of water, nutrient, or sunlight limitations.

15. PLANT PART PRODUCTIVITY

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.00	0.00	0.20	1.00	0.00	0.10
Soapweed	0.00	0.00	0.10	0.20	1.00	0.00
Crested wheatgrass	0.00	0.00	0.00	0.60	1.00	0.00
Western wheatgrass	0.00	0.00	0.10	0.30	1.00	0.00
Purple threeawn	0.00	0.00	0.00	0.00	1.00	0.00
Sideoats grama	0.00	0.00	0.10	0.10	1.00	0.00
Blue grama	0.00	0.00	0.00	0.00	1.00	0.00
Kentucky bluegrass	0.00	0.00	0.10	0.20	1.00	0.00
Little bluestem	0.00	0.00	0.10	0.20	1.00	0.00
Sacaton	0.00	0.00	0.10	0.10	1.00	0.00
Sand dropseed	0.00	0.00	0.00	0.00	1.00	0.00
Green needlegrass	0.00	0.00	0.00	0.20	1.00	0.00
Ragweed	0.00	0.00	0.00	0.10	1.00	0.00
Spotted knapweed	0.00	0.00	0.00	0.60	1.00	0.00
Canada thistle	0.00	0.00	0.00	0.20	1.00	0.00
Bindweed	0.00	0.00	0.00	0.20	1.00	0.00
Scarlet beeblossum	0.00	0.00	0.10	0.30	1.00	0.00
Golden aster	0.00	0.00	0.00	0.40	1.00	0.00
Hoarhound	0.00	0.00	0.10	0.20	1.00	0.00
Alfalfa	0.00	0.00	0.00	0.20	1.00	0.00
Orange globemallow	0.00	0.00	0.00	0.10	1.00	0.00
Mignonette	0.00	0.00	0.00	0.20	1.00	0.00
Wavyleaf thistle	0.00	0.00	0.00	0.20	1.00	0.00
Sweetclover	0.00	0.00	0.00	0.20	1.00	0.00
Japanese brome	0.00	0.00	0.20	0.40	1.00	0.00
Lambsquarters	0.00	0.00	0.10	0.50	1.00	0.00
Sunflower	0.00	0.00	0.00	0.60	1.00	0.00
Bladderpod	0.00	0.00	0.00	0.20	1.00	0.00
Russian thistle	0.00	0.00	0.00	0.60	1.00	0.00
Tansymustard	0.00	0.00	0.00	0.60	1.00	0.00

Photosynthesis occurs in some plants only in leaves. In other species, limited photosynthesis can occur in other parts, such as stems. This matrix provides the values used to calculate total photosynthetically-active biomass for a species. A value of 1.00 is assigned to leaves. This assumes that these are the most productive part of the plant. Values less than 1.00 are assigned to the other plant parts. These values are estimates of the relative (compared to leaves) photosynthetic rate of each of these parts.

To determine total potential production at each time step (day) in EDYS, the biomass of each plant part is multiplied by the respective value in Matrix 15, and then the product is multiplied times the daily potential growth rate (Matrix 13 value divided by 30, adjusted for month of the year).

16. GREEN-OUT PLANT PART PRODUCTIVITY FACTOR

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.10	0.00	0.10	0.50	1.00	0.00
Soapweed	0.05	0.00	0.10	0.10	0.20	0.00
Crested wheatgrass	0.00	0.00	0.20	0.50	1.00	0.00
Western wheatgrass	0.10	0.00	0.20	0.50	1.00	0.00
Purple threeawn	0.10	0.00	0.10	0.50	1.00	0.00
Sideoats grama	0.10	0.00	0.10	0.50	1.00	0.00
Blue grama	0.10	0.00	0.10	0.50	1.00	0.00
Kentucky bluegrass	0.10	0.00	0.30	0.50	1.00	0.00
Little bluestem	0.05	0.00	0.10	0.50	1.00	0.00
Sacaton	0.10	0.00	0.10	0.50	1.00	0.00
Sand dropseed	0.10	0.00	0.10	0.50	1.00	0.00
Green needlegrass	0.00	0.00	0.10	0.50	1.00	0.00
Ragweed	0.10	0.00	0.10	0.20	1.00	0.00
Spotted knapweed	0.00	0.00	0.20	0.50	1.00	0.00
Canada thistle	0.20	0.00	0.30	0.50	1.00	0.00
Bindweed	0.10	0.00	0.10	0.50	1.00	0.00
Scarlet beeblossum	0.10	0.00	0.10	0.20	1.00	0.00
Golden aster	0.10	0.00	0.10	0.20	1.00	0.00
Hoarhound	0.00	0.00	0.20	0.50	1.00	0.00
Alfalfa	0.10	0.00	0.10	0.50	1.00	0.00
Orange globemallow	0.30	0.00	0.10	0.50	1.00	0.00
Mignonette	0.05	0.00	0.20	0.50	1.00	0.00
Wavyleaf thistle	0.20	0.00	0.30	0.50	1.00	0.00
Sweetclover	0.05	0.00	0.20	0.50	1.00	0.00
Japanese brome	0.00	0.00	0.50	0.50	1.00	0.00
Lambsquarters	0.00	0.00	0.20	0.50	1.00	0.00
Sunflower	0.00	0.00	0.20	0.50	1.00	0.00
Bladderpod	0.10	0.00	0.20	0.50	1.00	0.00
Russian thistle	0.00	0.00	0.20	0.50	1.00	0.00
Tansymustard	0.00	0.00	0.20	0.50	1.00	0.00

Green-out (regrowth) occurs following dormancy or severe defoliation. Green-out is triggered by cessation of the factor that caused defoliation (e.g., winter, fire, heavy grazing, trampling). Under these conditions, regrowth is initially fueled by translocation of stored non-structural carbohydrates. Therefore, there is a temporary decrease in the biomass of the plant parts where these carbohydrates were stored. In effect, the stored carbohydrates are converted to new tissue.

This matrix specifies where these reserves are stored and how much is available for regrowth. A value of 1.00 indicates that an amount of new growth equal to the existing biomass of that plant part can be produced in one month. A value of 0.50 indicates that an amount of new growth equal of half of the existing biomass of that plant part can be produced in one month. In all cases, this does not mean that the existing biomass of the plant part is actually reduced by this amount, only that this is the potential new growth that can be generated from this existing biomass. The physiological process that occurs is that a given mass of carbohydrates are withdrawn from the stored reserves, used to produce the new leaf tissue, and most of these reserves are replaced from the production of photosynthates from the new leaves (Smith 1962, Garza 1994). The values in Matrix 16 simply indicate a net one-month production rate.

17. LIGHT COMPETITION FACTOR (SHADING)

Shading Species	Shaded Species																													
	Twist spine	Soap weed	Crest wgrass	West wgrass	Purple thawn	Side gram	Blue gram	Kent bgrass	Little bstem	Sac aton	Sand dseed	Green ngrass	Rag weed	Spot kweed	Can thstle	Bind weed	Scar bee	Gold aster	Hoar hound	Alf alfa	Mign onett	Ornge Gmallo	Wavy thstle	Sweet clovr	Jap brom	Lamb qrtrs	Sun flwer	Blddr pod	Russn thstle	Tnsy mstrd
Twistspine pricklypear	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Purple threeawn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sideoats grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Blue grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kentucky bluegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Little bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sacaton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green needlegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ragweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spotted knapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada thistle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bindweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scarlet beeblossum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hoarhound	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alfalfa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orange globemallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mignonette	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wavyleaf thistle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sweetclover	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Japanese brome	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lambsquarters	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bladderpod	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Russian thistle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tansymustard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Shading generally reduces the productivity of a shaded species, provided that the reduction in light intensity is sufficient. Commonly, there is no shading effect initially, as the shading species begins to grow, because the shading species has insufficient canopy development to significantly reduce the intensity of the sunlight. As the biomass of the shading species increases, the canopy coverage increases and the light intensity under the canopy decreases. In some cases, some shading is actually beneficial to the shaded species because the reduced sunlight results in lower temperatures and therefore lower transpirational water loss.

18. PHYSIOLOGICAL CONTROL CONSTRANTS

Species	Growing season max root:shoot	Growing season green-out shoot:root	Max 1-mo seed germination	Max 1st-mo seedling growth
Twistspine pricklypear	0.30	0.11	0.10	5
Soapweed	0.30	0.09	0.10	15
Crested wheatgrass	2.00	1.14	0.44	40
Western wheatgrass	3.00	0.14	0.69	30
Purple threeawn	1.30	0.05	0.80	30
Sideoats grama	2.00	0.09	0.34	40
Blue grama	1.90	0.26	0.66	60
Kentucky bluegrass	3.60	0.14	0.85	40
Little bluestem	2.40	0.21	0.53	30
Sacaton	0.90	0.87	0.80	40
Sand dropseed	10.00	0.10	0.40	70
Green needlegrass	10.00	0.11	0.40	50
Ragweed	1.30	0.39	0.64	30
Spotted knapweed	0.40	1.14	0.44	20
Canada thistle	3.10	0.16	0.56	20
Bindweed	0.90	0.25	0.60	15
Scarlet beeblossum	1.90	0.26	0.48	30
Golden aster	1.00	0.80	0.30	25
Hoarhound	3.00	0.17	0.44	40
Alfalfa	1.30	0.65	0.83	30
Orange globemallow	0.60	0.78	0.65	60
Mignonette	1.30	0.69	0.71	40
Wavyleaf thistle	3.10	0.16	0.56	40
Sweetclover	1.30	0.69	0.71	40
Japanese brome	0.70	0.84	0.75	25
Lambsquarters	0.70	0.75	0.96	40
Sunflower	0.40	1.14	0.44	40
Bladderpod	0.60	1.50	0.52	35
Russian thistle	0.30	3.32	0.44	40
Tansymustard	0.40	1.14	0.44	40

This matrix provides four physiological control factors that are used by EDYS to 1) keep above and belowground biomass within reasonable limits and 2) provide for seedling development.

The growing-season maximum root:shoot ratio value is used to prevent an imbalance occurring between above- and belowground biomass. If the root:shoot ratio exceeds this value, no growth allocation to roots takes place that month. This allows aboveground biomass to increase in relation to root biomass. The value for each species is set at twice the cumulative root:shoot ratio value (Matrix 01) for that species.

The growing-season green-out shoot:root ratio has a similar function, but it provides for a rapid readjustment between above- and belowground biomass. This can become necessary when a stressor (e.g., grazing, fire, mowing) causes a sudden removal of aboveground biomass. This is the green-out trigger mechanism between green-out month and winter dormancy (Matrix 10). If the shoot:root ratio becomes less than this value, green-out is triggered. The value for each species equals half of the inverse of the maximum root:shoot ratio.

Maximum one-month seed germination is the proportion of the seed bank for a particular species that can germinate in any single month of the seed germination months (Matrix 10). Most of the values were taken from, or estimated from Vories (1981), Fulbright et al. (1982), and Redente et al. (1982).

Maximum first-month seedling growth determines the maximum amount of biomass seedlings of each species can produce in the month of germination. The value in Matrix 18 is multiplied by the biomass of seeds of the respective species that germinate in that month (i.e., biomass in seed bank x maximum 1-month germination value). These values are estimates based on conceptual models of the relationships between 1-month-old seedling weights and the weight of the seed that produced the seedling.

19. END OF GROWING SEASON DIEBACK

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	0.05	0.15	0.05	0.05	0.05	1.00
Soapweed	0.03	0.10	0.03	0.02	0.02	1.00
Crested wheatgrass	0.10	0.21	0.05	1.00	1.00	1.00
Western wheatgrass	0.10	0.21	0.05	1.00	1.00	1.00
Purple threeawn	0.10	0.20	0.10	1.00	1.00	1.00
Sideoats grama	0.06	0.20	0.10	1.00	1.00	1.00
Blue grama	0.08	0.20	0.10	1.00	1.00	1.00
Kentucky bluegrass	0.10	0.20	0.10	0.90	1.00	1.00
Little bluestem	0.08	0.20	0.05	1.00	1.00	1.00
Sacaton	0.08	0.20	0.10	0.95	0.95	1.00
Sand dropseed	0.15	0.25	0.10	1.00	1.00	1.00
Green needlegrass	0.10	0.30	0.00	0.80	1.00	1.00
Ragweed	0.05	0.15	0.05	0.30	0.80	1.00
Spotted knapweed	0.70	0.80	0.80	0.95	0.95	1.00
Canada thistle	0.05	0.15	0.08	0.90	1.00	1.00
Bindweed	0.40	0.60	0.30	0.90	1.00	1.00
Scarlet beeblossum	0.10	0.20	0.15	0.80	1.00	1.00
Golden aster	0.10	0.20	0.10	0.10	1.00	1.00
Hoarhound	0.20	0.25	0.20	1.00	1.00	1.00
Alfalfa	0.05	0.15	0.05	0.95	0.95	1.00
Orange globemallow	0.30	0.50	0.20	1.00	1.00	1.00
Mignonette	0.40	0.60	0.30	0.90	1.00	1.00
Wavyleaf thistle	0.05	0.15	0.08	0.90	1.00	1.00
Sweetclover	0.40	0.60	0.30	0.90	1.00	1.00
Japanese brome	1.00	1.00	1.00	1.00	1.00	1.00
Lambsquarters	1.00	1.00	1.00	1.00	1.00	1.00
Sunflower	1.00	1.00	1.00	1.00	1.00	1.00
Bladderpod	1.00	1.00	1.00	1.00	1.00	1.00
Russian thistle	1.00	1.00	1.00	1.00	1.00	1.00
Tansymustard	1.00	1.00	1.00	1.00	1.00	1.00

This matrix provides the values for EDYS to calculate how much of each plant part component for each species dies at the end of each growing season. All (1.00) tissue of all parts of annuals die each year. For most herbaceous perennials, 100% of the leaves and stems die at the end of the growing season. Data used to calculate root survival was taken from Weaver (1954:160-162).

20. DIEBACK FATE

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds
Twistspine pricklypear	-1	-1	0	7	8	0
Soapweed	-1	-1	7	7	8	0
Crested wheatgrass	-1	-1	0	7	8	0
Western wheatgrass	-1	-1	0	7	8	0
Purple threeawn	-1	-1	0	7	8	0
Sideoats grama	-1	-1	0	7	8	0
Blue grama	-1	-1	0	7	8	0
Kentucky bluegrass	-1	-1	0	0	8	0
Little bluestem	-1	-1	0	7	8	0
Sacaton	-1	-1	0	7	8	0
Sand dropseed	-1	-1	0	7	8	0
Green needlegrass	-1	-1	0	7	8	0
Ragweed	-1	-1	7	7	0	0
Spotted knapweed	-1	-1	0	7	8	0
Canada thistle	-1	-1	0	7	8	0
Bindweed	-1	-1	0	0	0	0
Scarlet beeblossum	-1	-1	7	7	8	0
Golden aster	-1	-1	7	7	8	0
Hoarhound	-1	-1	0	7	0	0
Alfalfa	-1	-1	0	7	8	0
Orange globemallow	-1	-1	0	0	0	0
Mignonette	-1	-1	0	7	0	0
Wavyleaf thistle	-1	-1	0	7	8	0
Sweetclover	-1	-1	0	7	0	0
Japanese brome	-1	-1	0	7	8	0
Lambsquarters	-1	-1	0	7	0	0
Sunflower	-1	-1	0	7	8	0
Bladderpod	-1	-1	7	7	0	0
Russian thistle	-1	-1	0	7	8	0
Tansymustard	-1	-1	0	7	8	0

The purpose of this matrix is to designate which pool dead material from each plant part is initially placed. A designation of -1 places the dead material into the soil organic matter of the layer in which the material existed at the time of death. A designation of 0 places the material in surface litter, a value of 7 places the material in the standing dead stems compartment, and a value of 8 places the material into standing dead leaves.

21. PLANT PART LOSSES TO FIRE EVENTS

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Twistspine pricklypear	0.0	0.0	0.3	0.7	0.5	1.0	1.0	1.0	0.0	1.0	1.0
Soapweed	0.0	0.0	0.3	0.3	0.5	0.1	0.9	1.0	0.0	0.8	0.5
Crested wheatgrass	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Western wheatgrass	0.1	0.0	0.3	0.9	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Purple threeawn	0.0	0.0	0.4	0.9	1.0	1.0	1.0	1.0	0.0	1.0	1.0
Sideoats grama	0.0	0.0	0.1	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0
Blue grama	0.1	0.0	0.3	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0
Kentucky bluegrass	0.0	0.0	0.3	0.8	1.0	1.0	1.0	1.0	0.0	1.0	0.4
Little bluestem	0.0	0.0	0.3	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Sacaton	0.1	0.0	0.4	0.9	0.9	0.9	1.0	1.0	0.0	1.0	0.9
Sand dropseed	0.0	0.0	0.4	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0
Green needlegrass	0.0	0.0	0.5	0.9	1.0	1.0	1.0	1.0	0.0	1.0	0.2
Ragweed	0.0	0.0	0.7	0.8	1.0	1.0	1.0	1.0	0.0	1.0	1.0
Spotted knapweed	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Canada thistle	0.0	0.0	0.5	1.0	1.0	1.0	1.0	1.0	0.0	0.9	0.4
Bindweed	0.0	0.0	0.5	0.9	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Scarlet beeblossum	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Golden aster	0.0	0.0	0.7	0.9	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Hoarhound	0.0	0.0	0.6	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Alfalfa	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Orange globemallow	0.0	0.0	0.7	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0
Mignonette	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Wavyleaf thistle	0.0	0.0	0.5	1.0	1.0	1.0	1.0	1.0	0.0	0.9	0.4
Sweetclover	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Japanese brome	0.0	0.0	0.6	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.1
Lambsquarters	0.0	0.0	0.5	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Sunflower	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Bladderpod	0.0	0.0	0.7	1.0	1.0	0.8	1.0	1.0	0.0	1.0	0.5
Russian thistle	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Tansymustard	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5

This matrix designates how much of the biomass of each plant part of each species is lost in a moderate fire event, i.e., a relatively cool fire. A moderate fire event is defined as one in which the fuel load is 200 g/m^2 (1784 lbs/ac). The fuel load for this calculation is defined as the sum of the litter plus the non-trunk aboveground biomass of all herbaceous species.

The actual effectiveness of the fire (i.e., amount of biomass removed) is proportional to the calculated fuel load. At values below 200 g/m^2, no biomass is removed. At these light fuel loads, it is assumed that the fire does not carry through the plot. At 800 g/m^2 of fuel and higher, a crown fire is simulated, in which 90% of aboveground biomass is removed. Between 200 and 800 g/m^2, removal is proportional to the difference between 200 and 800. For example, at 500 g/m^2 of fuel, 45% of the standing dead stems and 45% of the leaves of live oak would be lost (90% x 10% x [200 + 800] / 2 = 45%). The value of 90% is used to account for intra-plot heterogeneity, i.e., it is assumed that 10% of a plot will remain unburned because of spatial variations in the fuel load.

The fuel load threshold values used (200 and 800 g/m^2) are typical values for cool and hot fires, respectively, from central and north Texas (Scifres 1980).

22. FUEL COMBUSTIBILITY FACTOR

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Twistspine pricklypear	0.0	0.0	0.5	0.2	0.8	1.0	0.8	1.0	0.0	0.8	1.0
Soapweed	0.0	0.0	0.3	0.3	0.5	0.8	1.5	1.5	0.0	0.6	1.0
Crested wheatgrass	0.0	0.0	0.5	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Western wheatgrass	0.0	0.0	1.0	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Purple threeawn	0.0	0.0	1.0	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Sideoats grama	0.5	0.4	0.8	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Blue grama	0.0	0.0	0.8	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Kentucky bluegrass	0.0	0.0	1.0	0.9	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Little bluestem	0.0	0.0	0.0	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Sacaton	0.0	0.0	0.9	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Sand dropseed	0.0	0.0	0.8	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Green needlegrass	0.0	0.0	1.0	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Ragweed	0.0	0.0	0.8	1.0	1.5	1.0	1.8	2.0	0.0	1.5	1.0
Spotted knapweed	0.0	0.0	0.5	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Canada thistle	0.0	0.0	1.0	1.0	1.2	1.0	1.5	1.8	0.0	1.0	1.0
Bindweed	0.0	0.0	0.8	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Scarlet beeblossum	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0
Golden aster	0.0	0.0	0.8	2.0	2.0	1.0	3.0	4.0	0.0	2.0	1.0
Hoarhound	0.0	0.0	0.0	1.0	1.1	1.0	1.5	1.5	0.0	1.0	1.0
Alfalfa	0.0	0.0	0.9	1.0	1.0	1.0	1.0	1.0	0.0	1.0	0.5
Orange globemallow	0.0	0.0	0.9	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Mignonette	0.0	0.0	0.9	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Wavyleaf thistle	0.0	0.0	1.0	1.0	1.2	1.0	1.5	1.8	0.0	1.0	1.0
Sweetclover	0.0	0.0	0.9	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Japanese brome	0.0	0.0	1.0	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Lambsquarters	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sunflower	0.0	0.0	0.5	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Bladderpod	0.0	0.0	1.0	1.0	1.5	1.0	1.5	2.0	0.0	1.5	1.0
Russian thistle	0.0	0.0	0.5	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0
Tansymustard	0.0	0.0	0.5	1.0	1.0	1.0	1.5	1.5	0.0	1.0	1.0

The effectiveness of a material in contributing to the fuel load is dependent on a number of factors, including 1) size of the material, 2) moisture content, 3) compaction, and 4) chemical composition (e.g., volatile oil content). Matrix 22 provides a measure of these factors in adjusting the effect of the fuel loads calculated using Matrix 21.

In Matrix 22, a value of 1.00 is typical of green fine fuel, such as grass leaves. A value of 1.50 is typical of dry fine fuel, such as dead grass leaves. Woody, or particularly lush herbaceous, materials have values less than 1.00. Material containing volatile oils, have values of 2.00, or greater, depending on moisture content.

23. PLANT LOSS TO TRAMPLING

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Twistspine pricklypear	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soapweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crested wheatgrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Western wheatgrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Purple threeawn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideoats grama	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blue grama	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kentucky bluegrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Little bluestem	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sacaton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sand dropseed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Green needlegrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ragweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spotted knapweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Canada thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bindweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scarlet beeblossum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Golden aster	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hoarhound	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alfalfa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Orange globemallow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mignonette	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wavyleaf thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sweetclover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Japanese brome	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lambsquarters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sunflower	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bladderpod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russian thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tansymustard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The values in Matrix 23 represent estimates of the physical impact of a single trampling event. A value of 0.50, for example, indicates that 50% of the biomass of that plant part is removed and transferred to the litter compartment. This matrix does not address whether or not the plant is killed by the trampling event. Survivability is simulated by the response of the plant to the tissue loss over time.

24. PLANT LOSS TO SINGLE VEHICLE PASS

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Twistspine pricklypear	0.00	0.00	0.50	0.10	0.00	0.50	0.90	0.90	0.20	0.05	0.00
Soapweed	0.00	0.00	0.70	0.90	0.80	0.95	0.95	0.80	0.20	0.80	0.00
Crested wheatgrass	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Western wheatgrass	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Purple threeawn	0.00	0.00	0.50	0.80	0.80	0.80	0.90	0.90	0.10	0.70	0.00
Sideoats grama	0.00	0.00	0.40	0.70	0.60	0.70	0.85	0.75	0.10	0.50	0.00
Blue grama	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Kentucky bluegrass	0.00	0.00	0.40	0.70	0.60	0.70	0.85	0.75	0.10	0.50	0.00
Little bluestem	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Sacaton	0.00	0.00	0.50	0.80	0.70	0.80	0.90	0.85	0.20	0.80	0.00
Sand dropseed	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Green needlegrass	0.00	0.00	0.50	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Ragweed	0.00	0.00	0.70	0.90	0.80	0.90	0.90	0.90	0.20	0.80	0.00
Spotted knapweed	0.00	0.00	0.50	0.80	0.70	0.80	0.90	0.85	0.20	0.80	0.00
Canada thistle	0.00	0.00	0.20	0.90	0.80	0.90	0.95	0.90	0.10	0.80	0.00
Bindweed	0.00	0.00	0.10	0.50	0.40	0.50	0.75	0.70	0.05	0.40	0.00
Scarlet beeblossum	0.00	0.00	0.70	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Golden aster	0.00	0.00	0.70	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Hoarhound	0.00	0.00	0.70	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Alfalfa	0.00	0.00	0.60	0.80	0.75	0.80	0.90	0.90	0.10	0.70	0.00
Orange globemallow	0.00	0.00	0.70	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Mignonette	0.00	0.00	0.70	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Wavyleaf thistle	0.00	0.00	0.60	0.90	0.75	0.90	0.95	0.85	0.10	0.60	0.00
Sweetclover	0.00	0.00	0.50	0.80	0.70	0.80	0.90	0.85	0.10	0.70	0.00
Japanese brome	0.00	0.00	0.50	0.80	0.70	0.80	0.85	0.85	0.10	0.70	0.00
Lambsquarters	0.00	0.00	0.70	0.90	0.80	0.90	0.95	0.90	0.20	0.80	0.00
Sunflower	0.00	0.00	0.70	0.90	0.90	0.90	0.95	0.95	0.20	0.80	0.00
Bladderpod	0.00	0.00	0.60	0.80	0.75	0.80	0.90	0.90	0.20	0.70	0.00
Russian thistle	0.00	0.00	0.60	0.80	0.70	0.80	0.90	0.85	0.20	0.70	0.00
Tansymustard	0.00	0.00	0.30	0.60	0.40	0.60	0.80	0.70	0.10	0.60	0.00

The values in Matrix 23 represent estimates of the physical impact of a single trampling event. A value of 0.50, for example, indicates that 50% of the biomass of that plant part is removed and transferred to the litter compartment. This matrix does not address whether or not the plant is killed by the trampling event. Survivability is simulated by the response of the plant to the tissue loss over time.

25. HERBIVORE PREFERENCE AND COMPETITION (P, C)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Insects											
Twistspine pricklypear	28,1	26,1	30,1	15,1	32,1	1,1	31,1	33,1	5,1	5,1	28,1
Soapweed	0,0	0,0	0,0	0,0	13,1	6,1	0,0	14,1	0,0	12,1	0,0
Crested wheatgrass	0,0	0,0	0,0	3,1	1,1	0,0	5,1	4,1	0,0	0,0	0,0
Western wheatgrass	0,0	0,0	0,0	3,1	1,1	0,0	5,1	4,1	0,0	0,0	0,0
Purple threeawn	27,1	25,1	18,1	14,1	4,1	10,1	25,1	22,1	4,1	3,1	28,1
Sideoats grama	27,1	25,1	16,1	12,1	2,1	8,1	23,1	20,1	2,1	1,1	28,1
Blue grama	27,1	25,1	15,1	11,1	1,1	7,1	24,1	20,1	3,1	2,1	28,1
Kentucky bluegrass	0,0	0,0	20,1	19,1	10,1	9,1	29,1	24,1	0,0	9,1	0,0
Little bluestem	0,0	0,0	8,1	7,1	1,1	6,1	0,1	13,1	0,1	1,1	0,1
Sacaton	22,1	21,1	23,1	23,1	10,1	11,1	24,1	12,1	20,1	9,1	12,1
Sand dropseed	27,1	25,1	15,1	13,1	2,1	8,1	24,1	21,1	3,1	2,1	28,1
Green needlegrass	0,0	0,0	0,0	3,1	1,1	0,0	5,1	4,1	0,0	0,0	0,0
Ragweed	28,1	26,1	32,1	29,1	7,1	10,1	33,1	21,1	4,1	3,1	28,1
Spotted knapweed	0,0	0,0	0,0	3,1	1,1	0,0	5,1	4,1	0,0	0,0	0,0
Canada thistle	0,0	0,0	24,1	24,1	21,1	10,1	28,1	27,1	0,0	20,1	0,0
Bindweed	0,0	0,0	7,1	7,1	1,1	2,1	12,1	10,1	0,0	1,1	0,0
Scarlet beeblossum	22,1	21,1	23,1	15,1	13,1	14,1	23,1	17,1	20,1	12,1	15,1
Golden aster	22,1	21,1	23,1	15,1	13,1	14,1	24,1	17,1	20,1	12,1	15,1
Hoarhound	0,0	0,0	9,1	4,1	2,1	3,1	0,1	13,1	0,1	1,1	0,1
Alfalfa	15,1	20,1	14,1	5,1	1,1	1,1	16,1	3,1	19,1	1,1	4,1
Orange globemallow	27,1	25,1	17,1	10,1	1,1	1,1	25,1	20,1	2,1	1,1	28,1
Mignonette	15,1	20,1	14,1	6,1	1,1	1,1	16,1	3,1	19,1	1,1	4,1
Wavyleaf thistle	0,0	0,0	24,1	24,1	21,1	10,1	28,1	27,1	0,0	20,1	0,0
Sweetclover	15,1	20,1	14,1	6,1	1,1	1,1	16,1	3,1	19,1	1,1	4,1
Japanese brome	0,0	0,0	7,1	7,1	3,1	4,1	11,1	7,1	0,0	3,1	0,0
Lambsquarters	0,3	0,3	0,3	4,3	3,1	5,3	0,3	0,3	0,3	1,1	0,2
Sunflower	0,0	0,0	0,0	3,1	1,1	0,0	5,1	4,1	0,0	0,0	0,0
Bladderpod	0,0	0,0	0,0	3,1	1,1	0,0	5,1	4,1	0,0	0,0	0,0
Russian thistle	15,1	20,1	16,1	11,1	4,1	4,1	17,1	16,1	19,1	3,1	5,1
Tansymustard	0,0	0,0	0,0	3,1	1,1	0,0	5,1	4,1	0,0	0,0	0,0
Rabbits											
Twistspine pricklypear	12,2	11,2	12,2	5,2	16,2	8,2	14,2	17,2	3,2	2,2	11,2
Soapweed	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Crested wheatgrass	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Western wheatgrass	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Purple threeawn	11,2	10,2	11,2	11,2	9,2	10,2	12,2	11,2	4,2	3,2	11,2
Sideoats grama	11,2	10,2	8,2	8,2	2,2	2,2	9,2	6,2	3,2	2,2	9,2
Blue grama	11,2	10,2	10,2	9,2	2,2	2,2	10,2	7,2	3,2	2,2	9,2
Kentucky bluegrass	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Little bluestem	0,0	0,0	6,2	5,2	3,2	5,2	10,2	5,2	0,0	2,2	0,0
Sacaton	10,2	9,2	15,2	10,2	7,2	7,2	14,2	12,2	7,2	5,2	7,2

25. HERBIVORE PREFERENCE AND COMPETITION (P, C) (cont.)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Rabbits											
Sand dropseed	11,2	10,2	9,2	9,2	3,2	2,2	10,2	7,2	3,2	2,2	9,2
Green needlegrass	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Ragweed	12,2	11,2	14,2	10,2	9,2	8,2	15,2	11,2	3,2	2,2	11,2
Spotted knapweed	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Canada thistle	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Bindweed	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Scarlet beeblossum	19,2	18,2	22,2	19,2	16,2	13,2	29,2	21,2	16,2	14,2	13,2
Golden aster	19,2	18,2	22,2	19,2	16,2	13,2	29,2	20,2	16,2	14,2	13,2
Hoarhound	0,0	0,0	5,2	2,2	1,2	2,2	8,2	5,2	0,0	1,2	0,0
Alfalfa	8,2	9,2	12,2	3,2	1,2	1,2	14,2	5,2	7,2	1,2	2,2
Orange globemallow	11,2	10,2	7,2	1,2	1,2	1,2	10,2	6,2	2,2	1,2	9,2
Mignonette	9,2	9,2	13,2	4,2	2,2	1,2	15,2	6,2	7,2	2,2	3,2
Wavyleaf thistle	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Sweetclover	9,2	9,2	13,2	4,2	2,2	1,2	15,2	6,2	7,2	2,2	3,2
Japanese brome	0,0	0,0	6,2	6,2	5,2	4,2	8,2	7,2	0,0	4,2	0,0
Lambsquarters	7,1	7,1	7,1	6,1	6,2	5,1	0,3	0,3	7,1	2,1	0,1
Sunflower	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Bladderpod	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0
Russian thistle	10,2	9,2	15,2	7,2	7,2	7,2	21,2	21,2	7,2	3,2	7,2
Tansymustard	0,0	0,0	0,0	3,2	1,2	0,0	5,2	4,2	0,0	0,0	0,0

25. HERBIVORE PREFERENCE AND COMPETITION (P, C) (Continued)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Horses											
Twistspine pricklypear	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Soapweed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Crested wheatgrass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Western wheatgrass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Purple threeawn	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sideoats grama	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Blue grama	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Kentucky bluegrass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Little bluestem	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sacaton	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sand dropseed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Green needlegrass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Ragweed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Spotted knapweed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Canada thistle	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Bindweed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Scarlet beeblossum	30,4	30,4	29,4	23,4	23,4	21,4	26,4	26,4	30,4	21,4	12,4
Golden aster	31,4	31,4	30,4	24,4	24,4	13,4	26,4	26,4	30,4	21,4	13,4
Hoarhound	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Alfalfa	19,4	19,4	18,4	1,4	1,4	1,4	2,4	2,4	19,4	1,4	3,4
Orange globemallow	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Mignonette	19,4	19,4	18,4	4,4	3,4	3,4	5,4	4,4	19,4	2,4	4,4
Wavyleaf thistle	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sweetclover	19,4	19,4	18,4	4,4	3,4	3,4	5,4	4,4	19,4	2,4	4,4
Japanese brome	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Lambsquarters	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Sunflower	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Bladderpod	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Russian thistle	20,4	21,4	20,4	6,4	6,4	6,4	23,4	23,4	20,4	3,4	6,4
Tansymustard	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Cattle											
Twistspine pricklypear	14,3	12,3	14,3	3,3	21,3	5,3	17,3	22,3	2,3	1,3	8,3
Soapweed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Crested wheatgrass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Western wheatgrass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Purple threeawn	13,3	11,3	9,3	4,3	4,3	4,3	4,3	4,3	3,3	2,3	2,3
Sideoats grama	13,3	11,3	8,3	1,3	1,3	1,3	1,3	1,3	2,3	1,3	7,3
Blue grama	13,3	11,3	9,3	1,3	1,3	1,3	1,3	1,3	2,3	1,3	6,3
Kentucky bluegrass	0,0	0,0	5,5	4,5	4,5	4,5	5,5	5,5	0,0	3,5	0,0
Little bluestem	0,0	0,0	4,4	3,4	3,4	3,4	4,4	4,4	0,0	3,4	0,0
Sacaton	7,5	7,5	7,5	2,5	2,5	2,5	5,5	5,5	1,5	1,5	5,5
Sand dropseed	13,3	11,3	9,3	2,3	2,3	2,3	2,3	2,3	2,3	1,3	6,3
Green needlegrass	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Ragweed	14,3	12,3	18,3	16,3	8,3	8,3	18,3	13,3	7,3	6,3	8,3
Spotted knapweed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Canada thistle	0,0	0,0	10,5	9,5	9,5	6,5	10,5	10,5	0,0	8,5	0,0

25. HERBIVORE PREFERENCE AND COMPETITION (P, C) (Continued)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Cattle											
Bindweed	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Scarlet beeblossum	29,5	29,5	29,5	22,5	22,5	21,5	25,5	25,5	20,5	20,5	12,5
Golden aster	30,5	30,5	30,5	23,5	23,5	13,5	25,5	25,5	20,5	20,5	13,5
Hoarhound	0,0	0,0	6,4	5,4	5,4	5,4	7,4	7,4	0,0	5,4	0,0
Alfalfa	19,5	19,5	19,5	1,5	1,5	1,5	2,5	2,5	1,5	1,5	3,5
Orange globemallow	13,3	11,3	10,3	5,3	5,3	5,3	5,3	5,3	2,3	1,3	7,3
Mignonette	19,5	19,5	19,5	4,5	4,5	4,5	5,5	5,5	2,5	2,5	4,5
Wavyleaf thistle	0,0	0,0	10,5	9,5	9,5	6,5	10,5	10,5	0,0	8,5	0,0
Sweetclover	19,5	19,5	19,5	4,5	4,5	4,5	5,5	5,5	2,5	2,5	4,5
Japanese brome	0,0	0,0	7,4	6,4	6,4	6,4	8,4	8,4	0,0	6,4	0,0
Lambsquarters	0,2	0,2	9,2	6,2	9,3	7,2	0,3	0,3	0,2	2,3	0,3
Sunflower	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Bladderpod	0,0	0,0	0,0	5,4	5,4	0,0	7,4	6,4	0,0	0,0	0,0
Russian thistle	20,5	20,5	20,5	6,5	6,5	6,5	22,5	22,5	3,5	3,5	6,5
Tansymustard	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Herbivory is simulated in EDYS as a species-specific and a plant part-specific process. Each species of herbivore selects various plant species, based on the preference of that herbivore and the availability of the plant species. In addition, each herbivore also selects individual plant parts of individual species based on preference and availability.

The first number of each pair in Matrix 24 is the relative preference value for that plant part of that species for a specific herbivore. Sideoats grama is more preferred than is Japanese brome, provided each of these species have new growth available. Little bluestem is less preferred by cattle than is sideoats grama. However, if the only sideoats forage that is available is old growth (standing dead leaves and stems) and new growth of little bluestem is available, cattle will select little bluestem over sideoats.

The second number of each pair in Matrix 24 is the relative competition value for each plant part of each species for each herbivore. This value is used to determine which herbivore gets first choice of that plant part, when more than one herbivore attempts to select it and there is insufficient amount to supply both herbivores. In most cases, this value assumes that if the material is limited, insects are most likely to acquire the limited resource, followed by rabbits, and then cattle.

26. HERBIVORE ACCESSIBILITY

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Insects											
Twistspine pricklypear	0	1	2	10	99	99	10	99	0	90	10
Soapweed	0	0	100	100	100	100	100	100	0	100	40
Crested wheatgrass	0	0	0	100	100	0	100	100	0	0	0
Western wheatgrass	0	0	0	100	100	0	100	100	0	0	0
Purple threeawn	0	1	90	95	99	99	95	99	0	90	5
Sideoats grama	0	1	90	95	99	99	95	99	0	90	5
Blue grama	0	1	85	95	99	99	95	99	0	90	5
Kentucky bluegrass	0	0	90	100	100	100	100	100	0	100	5
Little bluestem	0	0	40	90	90	90	90	90	0	90	10
Sacaton	0	0	50	80	90	90	80	90	0	80	0
Sand dropseed	0	1	90	95	99	99	95	99	0	90	5
Green needlegrass	0	0	0	100	100	0	100	100	0	0	0
Ragweed	0	1	2	5	99	99	5	80	0	90	5
Spotted knapweed	0	0	0	100	100	0	100	100	0	0	0
Canada thistle	0	0	90	100	100	100	100	100	0	100	20
Bindweed	0	0	100	100	100	100	100	100	0	100	5
Scarlet beeblossum	0	0	10	50	99	99	10	99	0	99	0
Golden aster	0	0	0	20	99	99	0	99	0	99	0
Hoarhound	0	0	90	90	90	90	90	90	0	90	0
Alfalfa	0	0	90	99	99	99	99	99	0	99	0
Orange globemallow	0	1	95	95	99	99	95	99	0	90	5
Mignonette	0	0	90	99	99	99	99	99	0	99	0
Wavyleaf thistle	0	0	90	100	100	100	100	100	0	100	20
Sweetclover	0	0	90	99	99	99	99	99	0	99	0
Japanese brome	0	0	80	100	100	100	100	100	0	100	10
Lambsquarters	0	0	50	100	100	90	100	100	0	100	50
Sunflower	0	0	0	100	100	0	100	100	0	0	0
Bladderpod	0	0	0	100	100	0	100	100	0	0	0
Russian thistle	0	0	90	99	99	99	99	99	0	99	0
Tansymustard	0	0	0	100	100	0	100	100	0	0	0
Rabbits											
Twistspine pricklypear	1	1	90	50	50	50	50	50	5	95	1
Soapweed	0	0	0	100	100	0	100	100	0	0	0
Crested wheatgrass	0	0	0	100	100	0	100	100	0	0	0
Western wheatgrass	0	0	0	100	100	0	100	100	0	0	0
Purple threeawn	1	1	90	95	95	99	95	95	5	80	1
Sideoats grama	1	1	90	95	99	99	95	99	5	80	1
Blue grama	1	1	85	95	95	95	95	95	5	80	5
Kentucky bluegrass	0	0	0	100	100	0	100	100	0	0	0
Little bluestem	5	0	80	90	90	90	90	90	0	90	0
Sacaton	5	1	80	90	90	90	90	80	10	80	0
Sand dropseed	1	1	90	95	99	95	95	99	5	80	1
Green needlegrass	0	0	0	100	100	0	100	100	0	0	0
Ragweed	1	1	10	80	90	90	80	90	5	90	1

26. HERBIVORE ACCESSIBILITY (cont.)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
<u>Rabbits</u>											
Spotted knapweed	0	0	0	100	100	0	100	100	0	0	0
Canada thistle	0	0	0	100	100	0	100	100	0	0	0
Bindweed	0	0	0	100	100	0	100	100	0	0	0
Scarlet beeblossum	5	2	99	99	99	99	99	90	50	80	0
Golden aster	5	2	99	90	90	95	90	80	60	95	0
Hoarhound	5	0	90	90	90	90	90	90	0	90	0
Alfalfa	5	1	90	99	99	99	99	90	10	90	1
Orange globemallow	1	1	95	99	99	99	99	99	5	80	2
Mignonette	5	1	90	99	99	99	99	90	10	90	1
Wavyleaf thistle	0	0	0	100	100	0	100	100	0	0	0
Sweetclover	5	1	90	99	99	99	99	90	10	90	1
Japanese brome	5	0	100	100	100	100	100	100	0	100	0
Lambsquarters	15	15	50	100	90	90	100	90	15	100	20
Sunflower	0	0	0	100	100	0	100	100	0	0	0
Bladderpod	0	0	0	100	100	0	100	100	0	0	0
Russian thistle	5	1	90	99	99	99	99	90	10	90	0
Tansymustard	0	0	0	100	100	0	100	100	0	0	0

26. HERBIVORE ACCESSIBILITY (Continued)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Horses											
Twistspine pricklypear	0	0	0	0	0	0	0	0	0	0	0
Soapweed	0	0	0	0	0	0	0	0	0	0	0
Crested wheatgrass	0	0	0	0	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0	0	0	0	0
Purple threeawn	0	0	0	0	0	0	0	0	0	0	0
Sideoats grama	0	0	0	0	0	0	0	0	0	0	0
Blue grama	0	0	0	0	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	0	0	0	0	0	0	0	0	0
Little bluestem	0	0	0	0	0	0	0	0	0	0	0
Sacaton	0	0	0	0	0	0	0	0	0	0	0
Sand dropseed	0	0	0	0	0	0	0	0	0	0	0
Green needlegrass	0	0	0	0	0	0	0	0	0	0	0
Ragweed	0	0	0	0	0	0	0	0	0	0	0
Spotted knapweed	0	0	0	0	0	0	0	0	0	0	0
Canada thistle	0	0	0	0	0	0	0	0	0	0	0
Bindweed	0	0	0	0	0	0	0	0	0	0	0
Scarlet beeblossum	1	0	50	95	95	80	95	90	3	60	0
Golden aster	1	0	99	99	60	95	99	50	4	80	0
Hoarhound	0	0	0	0	0	0	0	0	0	0	0
Alfalfa	0	0	90	95	95	99	95	90	4	80	0
Orange globemallow	0	0	0	0	0	0	0	0	0	0	0
Mignonette	0	0	90	95	95	99	95	90	4	80	0
Wavyleaf thistle	0	0	0	0	0	0	0	0	0	0	0
Sweetclover	0	0	90	95	95	99	95	90	4	80	0
Japanese brome	0	0	0	0	0	0	0	0	0	0	0
Lambsquarters	0	0	0	0	0	0	0	0	0	0	0
Sunflower	0	0	0	0	0	0	0	0	0	0	0
Bladderpod	0	0	0	0	0	0	0	0	0	0	0
Russian thistle	0	0	90	95	95	99	95	90	2	50	0
Tansymustard	0	0	0	0	0	0	0	0	0	0	0
Cattle											
Twistspine pricklypear	1	0	20	5	0	60	5	0	0	40	0
Soapweed	0	0	0	0	0	0	0	0	0	0	0
Crested wheatgrass	0	0	0	0	0	0	0	0	0	0	0
Western wheatgrass	0	0	0	0	0	0	0	0	0	0	0
Purple threeawn	0	0	40	90	90	95	90	90	0	5	0
Sideoats grama	0	0	10	80	80	95	80	80	0	5	0
Blue grama	0	0	40	80	90	95	80	90	0	10	0
Kentucky bluegrass	0	0	40	100	80	100	100	80	0	30	0
Little bluestem	0	0	40	90	90	90	90	90	0	50	0
Sacaton	0	0	40	70	80	90	70	80	40	50	0
Sand dropseed	0	0	40	90	90	95	90	90	0	2	0
Green needlegrass	0	0	0	0	0	0	0	0	0	0	0
Ragweed	1	0	5	60	20	50	60	20	0	20	0
Spotted knapweed	0	0	0	0	0	0	0	0	0	0	0
Canada thistle	0	0	0	90	90	100	90	90	0	20	0

26. HERBIVORE ACCESSIBILITY (Continued)

Species	CRoot	FRoot	Trunk	Stems	Leaves	Seeds	SD Stems	SD Leaves	Sdlg Root	Sdlg Shoot	Seed Bank
Cattle											
Bindweed	0	0	0	0	0	0	0	0	0	0	0
Scarlet beeblossum	1	0	30	90	90	75	90	90	15	60	0
Golden aster	1	0	99	99	60	95	99	50	20	80	0
Hoarhound	0	0	90	90	90	90	90	90	0	20	0
Alfalfa	0	0	70	80	90	90	80	70	40	80	0
Orange globemallow	0	0	40	90	90	95	90	90	0	2	0
Mignonette	0	0	70	80	90	90	80	70	40	80	0
Wavyleaf thistle	0	0	0	90	90	100	90	90	0	20	0
Sweetclover	0	0	70	80	90	90	80	70	40	80	0
Japanese brome	0	0	80	100	100	100	100	100	0	50	0
Lambsquarters	10	10	90	90	90	80	90	90	10	50	0
Sunflower	0	0	0	0	0	0	0	0	0	0	0
Bladderpod	0	0	0	100	100	0	100	100	0	0	0
Russian thistle	0	0	60	80	80	80	80	60	40	50	0
Tansymustard	0	0	0	0	0	0	0	0	0	0	0

Another important aspect of determining herbivore diets is accessibility. This relates to how much of a particular plant part an herbivore could select if it wanted the plant part. A high value in Matrix 25 does not suggest that the herbivore would actually select that plant part. Selection is largely determined by preference (Matrix 24).

27. INITIAL BIOMASS

Species	C100	C200	C300	C400	C500	C600	C700	C800
Twistspine pricklypear	0.00	0.00	0.00	0.20	4.16	0.00	0.00	0.00
Soapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western wheatgrass	0.00	9.74	5.94	6.76	71.26	60.19	42.85	52.89
Purple threeawn	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00
Sideoats grama	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00
Blue grama	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Kentucky bluegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.33
Little bluestem	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sacaton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sand dropseed	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Green needlegrass	0.00	15.22	46.19	78.10	45.65	45.65	30.43	30.43
Ragweed	0.00	0.03	0.13	0.00	0.16	0.00	0.00	0.00
Spotted knapweed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada thistle	0.00	4.27	0.08	2.75	2.10	0.83	7.84	0.00
Bindweed	12.38	22.18	12.62	21.78	23.24	27.46	24.14	30.22
Scarlet beeblossum	1.13	7.19	3.06	5.60	4.17	2.60	1.27	1.23
Golden aster	0.00	0.00	0.39	0.19	0.07	0.00	0.00	0.07
Hoarhound	0.34	5.69	1.80	1.75	2.54	0.00	5.13	1.26
Alfalfa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orange globemallow	0.04	0.03	0.12	0.46	0.07	0.00	0.06	0.06
Mignonette	1.84	36.09	35.80	34.42	25.26	17.03	16.51	10.65
Wavyleaf thistle	0.00	14.54	0.24	0.09	0.00	0.00	0.00	6.69
Sweetclover	1.40	0.10	0.28	0.03	0.00	0.00	0.02	0.12
Japanese brome	1.62	0.80	0.73	5.17	12.13	5.21	3.60	4.75
Lambsquarters	0.10	0.39	0.11	0.06	0.12	0.07	0.05	0.02
Sunflower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bladderpod	0.38	0.05	0.06	0.12	0.09	0.00	0.25	0.04
Russian thistle	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00
Tansymustard	0.66	0.08	0.13	0.37	0.06	0.11	0.16	0.46

27. INITIAL BIOMASS (cont.)

Species	C900	C1000	C1100	C1200	C1300	C1400	C1500	C1600
Twistspine pricklypear	2.04	3.61	2.36	1.87	1.86	0.62	0.68	2.75
Soapweed	4.66	3.12	0.50	0.67	0.30	7.32	0.54	0.00
Crested wheatgrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Western wheatgrass	5.24	0.26	1.36	0.53	0.76	1.52	1.78	3.35
Purple threeawn	0.00	13.12	8.47	0.49	5.06	2.75	6.17	0.97
Sideoats grama	1.08	5.45	5.44	2.56	3.77	4.33	9.44	5.81
Blue grama	0.00	3.32	0.54	0.00	0.36	1.40	1.08	0.00
Kentucky bluegrass	6.22	0.13	0.00	0.00	0.18	0.13	0.51	0.14
Little bluestem	0.00	0.26	1.20	0.11	1.37	0.35	1.97	0.00
Sacaton	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00
Sand dropseed	1.70	0.56	0.97	0.43	0.12	0.12	1.02	0.62
Green needlegrass	30.43	0.00	0.00	0.00	0.00	0.00	0.00	1.83
Ragweed	0.00	0.29	0.41	0.13	0.11	0.56	0.28	0.23
Spotted knapweed	33.06	33.06	33.06	72.74	33.06	33.06	33.06	39.68
Canada thistle	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00
Bindweed	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Scarlet beeblossum	0.32	0.45	0.42	0.38	0.83	0.39	0.69	0.13
Golden aster	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hoarhound	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alfalfa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orange globemallow	0.53	0.23	0.11	0.20	0.04	0.12	0.07	0.60
Mignonette	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wavyleaf thistle	0.00	0.00	0.22	0.00	0.00	0.05	0.00	0.04
Sweetclover	4.02	17.23	16.40	8.24	6.31	13.90	18.34	14.07
Japanese brome	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lambsquarters	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sunflower	0.00	0.04	0.08	0.21	0.21	0.00	0.22	0.40
Bladderpod	0.00	0.00	0.00	0.00	0.00	0.33	0.10	0.00
Russian thistle	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00
Tansymustard	0.00	0.09	0.00	0.19	0.00	0.00	0.00	0.00

These are the initial aboveground biomass values used to begin an EDYS simulation. The values for each community were based on the data collected in the field treatment plots.

Appendix Table 1. Sources of root:shoot ratios used in the EDYS application for Fort Carson, Colorado.

Species	Source
Twistspine pricklypear	*Opuntia echinocarpa* (Garcia-Moya & McKell 1970)
Soapweed	*Yucca elata* (Ludwig 1977)
Crested wheatgrass	Svejcar (1990)
Western wheatgrass	Burlson and Hewitt (1982), Kemp and Williams (1980), Mack (1986), Mueller and Bowman (1989), Samuel and Hart (1992), Vinton and Burke (1995)
Purple threeawn	Vinton and Burke (1995), Fernandez and Reynolds (2000)
Sideoats grama	Fick and Moser (1978)
Blue grama	Kemp and Williams (1980), Mata-Gonzalez et al. (2002)
Kentucky bluegrass	Davidson (1969), Tilman and Wedin (1991)
Little bluestem	Cerligione et al. (1987), Tilman and Wedin (1991)
Sacaton	de Alba and Cox (1988), Novoplansky and Goldberg (2001)
Sand dropseed	*Sporobolus flexosus* (Fernandez and Reynolds 2000)
Green needlegrass	*Stipa comata* (Blank and Young 1998, Burleson and Hewitt 1982, Vinton and Burke 1995)
Ragweed	*Ambrosia dumosa* (Garcia-Moya and McKell 1970, Wallace et al. 1974)
Spotted knapweed	Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Canada thistle	Ziska (2003)
Bindweed	Ziska (2003)
Scarlet beeblossum	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Golden aster	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Hoarhound	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Alfalfa	Bray (1963), Holechek (1982)
Mignonette	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Orange globemallow	*Centaurea maculosa* - Jacobs and Sheley (1997), Olson and Wallander (1997), Velegala et al. (1997)
Wavyleaf thistle	*Cirsium arvense* (Ziska 2003)
Sweetclover	*Trifolium repens* (Davidson 1969)
Japanese brome	*B. tectorum* (Aquirre and Johnson 1991, Arrendondo et al. 1998, Blank and Young 1998, DeLucia et al. 1989, Hinds 1975, Link et al. 1990, Lowe et al. 2002, Sheley and Larson 1994, Svejcar 1990)
Lambsquarters	Salsola kali (Dwyer and Wolde-Yohannis 1972, Redente et al. 1992)
Sunflower	Gutschick 1993
Bladderpod	Annual – Odum (1971)
Russian thistle	Redente et al. (1992), Dwyer and Wolde-Yohannis (1972)
Tansymustard	Annual – Odum (1971)

Data from the following studies were used to calculate root:shoot ratios:
Aguirre and Johnson 1991, Andersson 1970, Arrendondo et al. 1998, Beaty et al. 1975, Blank and Young 1998, Burlson and Hewitt 1982, Cerligione et al. 1987, Coupland and Johnson 1965, Coyne and Bradford 1986, Davidson 1969, DeLucia et al. 1989, Detling et al. 1979, Duvigneaud et al. 1971, Dwyer and Wolde-Yohannis 1972, Eissenstat 1990, Foster et al. 1980, Ganskopp 1988, Gigon and Rorison 1972, Groot et al. 1998, Haystead et al. 1988, Hellmers et al. 1955, Hetrick et al. 1990, Hinds 1975, Hironaka and Sindelar 1975, Holechek 1982, Hons et al. 1979, Johnson et al. 1989, Kemp and Williams 1980, Kramer 1969, Link et al. 1990, Mack 1986, McDermot 1954, McGinnies and Crofts 1986, McNeill and Wood 1990, Mohammad et al. 1982, Mueller and Bowman 1989, Nadelhoffer et al. 1985, Nasri and Doescher 1995, Niller 1990, Orodho 1990, Pande and Singh 1981, Patterson 1992, Redente et al. 1992, Reichman and Smith 1991, Samuel and Hart 1992, Santantonio et al. 1977, Sheley and Larson 1994, Shipley and Peters 1990, Smith 1982, Svejcar 1990, Tiedemann 1986, Tilman and Wedin 1991, Velagala et al. 1997, Vinton and Burke 1995, Weaver and Zink 1946, White and Van Auken 1996, Whittaker and Woodwell 1969, and Williams et al. 1995.

Appendix Table 2.   Sources of root architecture data.

Species	Reference
<u>Shrubs</u>	
Twistspine pricklypear (*Opuntia macrorhiza*)	*Opuntia imbricata* (Cottle 1931, Dittmer 1959)
Soapweed (*Yucca glauca*)	*Yucca elata* (Gibbens and Lenz 2001)
<u>Grasses</u>	
Crested wheatgrass (*Agropyron cristatum*)	Caldwell and Richards (1990)
Western wheatgrass (*Pascopyrum smithii)*	Weaver and Darland (1949), Hopkins (1953), Weaver (1958)
Purple threeawn (*Aristida purpurea*)	Gibbens and Lenz 2001
Sideoats grama (*Bouteloua curtipendula*)	Weaver and Darland (1949), Hopkins (1953)
Blue grama (*Bouteloua gracilis*)	Cottle (1931), Weaver (1947), Weaver and Zink (1947), Weaver and Darland (1949), Hopkins (1953), Weaver (1958, 1968), Lee and Lauenroth (1994)
Kentucky bluegrass (*Poa pratensis*)	Weaver and Darland (1949), Hopkins (1953)
Little bluestem (*Schizachyrium scoparium*)	Weaver (1947), Weaver and Zink (1947), Weaver and Darland (1949), Coupland and Brayshaw (1953), Weaver (1958, 1968)
Sacaton (*Sporobolus airoides*)	*Sporobolus cryptandrus* (Albertson 1937, Hopkins 1953)
Sand dropseed (*Sporobolus cryptandrus*)	Albertson (1937), Hopkins (1953)
Green needlegrass (*Stipa viridula*)	*Stipa comata* – Melgoza and Nowak (1991); *Stipa spartea* – Coupland and Brayshaw (1953), Weaver (1968)
Japanese brome (*Bromus japonicus*)	*Bromus tectorum* (Cline et al. 1977)
<u>Forbs</u>	
Ragweed (*Ambrosia psilostachya*)	*Ambrosia dumosa* (Wallace et al. 1980)
Spotted knapweed (*Centaurea maculosa*)	Marler et al. (1999)
Canada thistle (*Cirsium arvensis*)	*Centaurea maculosa* (Marler et al. 1999)
Bindweed (*Convolvulus arvensis*)	*Centaurea maculosa* (Marler et al. 1999)
Scarlet beeblossum (*Gaura coccinea*)	Gibbens and Lenz 2001
Golden aster (*Heterotheca villosa*)	*Centaurea maculosa* (Marler et al. 1999)
Hoarhound (*Marrubium vulgare*)	*Centaurea maculosa* (Marler et al. 1999)
Alfalfa (*Medicago sativa*)	Rasse et al. (2000)
Mignonette (*Reseda lutea*)	*Centaurea maculosa* (Marler et al. 1999)
Orange globemallow (*Sphaeralcea coccinea*)	*Sphaeralcea hastulata* (Gibbens and Lenz 2001)
Wavyleaf thistle (*Cirsium undulatum*)	*Centaurea maculosa* (Marler et al. 1999)
Sweetclover (*Melilotus officinalis*)	*Centaurea maculosa* (Marler et al. 1999)
Lambsquarters (*Chenopodium album*)	*Salsola kali* (Pan et al. 2001)
Sunflower (*Helianthus petiolaris*)	Stone et al. (2001)
Bladderpod (*Lesquerella montana*)	*Centaurea maculosa* (Marler et al. 1999)
Russian thistle (*Salsola kali*)	Pan et al. (2001)
Tansymustard (*Sisymbrium altissimum*)	Weaver (1977)

Appendix Table 3. Maximum reported rooting depths (cm).

Species	Depth	Reference
Shrubs		
Twistspine pricklypear (*Opuntia macrorhiza*)	130	*Opuntia ramosissima* – Rundel and Nobel (1991)
Soapweed (*Yucca glauca*)	60	Sosebee et al. 1982
Grasses		
Crested wheatgrass (*Agropyron cristatum*)	148	Cook and Lewis (1963)
Western wheatgrass (*Pascopyrum smithii)*	360	Hopkins (1953)
Purple threeawn (*Aristida purpurea*)	183	Albertson (1937)
Sideoats grama (*Bouteloua curtipendula*)	396	Tomanek and Albertson (1957)
Blue grama (*Bouteloua gracilis*)	213	Hopkins (1953)
Kentucky bluegrass (*Poa pratensis*)	213	Weaver (1920)
Little bluestem (*Schizachyrium scoparium*)	216	Weaver and Clements (1938)
Sacaton (*Sporobolus airoides*)	270	*Sporobolus cryptandrus* (Weaver and Hansen 1939)
Sand dropseed (*Sporobolus cryptandrus*)	270	Weaver and Hansen (1939)
Green needlegrass (*Stipa viridula*)	365	*Stipa comata* (Wyatt et al. 1980)
Japanese brome (*Bromus japonicus*)	152	Bromus tecturum (Hulbert 1955)
Forbs		
Ragweed (*Ambrosia psilostachya*)	183	Weaver (1958)
Spotted knapweed (*Centaurea maculosa*)	77	*Centaurea solsticialis* (Sheley and Larson 1994)
Canada thistle (*Cirsium arvensis*)	410	*Sphaeralcea coccinea* (Tomanek and Albertson 1957)
Bindweed (*Convolvulus arvensis*)	410	*Sphaeralcea coccinea* (Tomanek and Albertson 1957)
Scarlet beeblossum (*Gaura coccinea*)	305	Hopkins (1951)
Golden aster (*Heterotheca villosa*)	213	*Aster ericoides* (Hopkins 1951)
Hoarhound (*Marrubium vulgare*)	156	*Mentzelia nuda* (Weaver 1958)
Alfalfa (*Medicago sativa*)	900	Kramer (1969)
Mignonette (*Reseda lutea*)	213	*Aster ericoides* (Hopkins 1951)
Orange globemallow (*Sphaeralcea coccinea*)	410	Tomanek and Albertson (1957)
Wavyleaf thistle (*Cirsium undulatum*)	410	*Sphaeralcea coccinea* (Tomanek and Albertson 1957)
Sweetclover (*Melilotus officinalis*)	140	Wyatt et al. (1980)
Lambsquarters (*Chenopodium album*)	119	Cole and Hoch (1941)
Sunflower (*Helianthus petiolaris*)	76	*Helianthus pauciflorus* (Tolstead 1942)
Bladderpod (*Lesquerella montana*)	200	Salsola kali (Holm et al. 1997)
Russian thistle (*Salsola kali*)	200	Holm et al. (1997)
Tansymustard (*Sisymbrium altissimum*)	70	Renz et al. (1997)

Appendix Table 4. Water-use efficiency (WUE) values (kg of water required to produce 1 g of plant dry-weight biomass).

Species	WUE	Source
Shrubs		
Twistspine pricklypear (*Opuntia macrorhiza*)	0.16 - 0.29	*Opuntia ellisiana* (Han and Felker 1997), *Opuntia basilaris* (Szarek and Ting 1974)
Soapweed (*Yucca glauca*)	0.51	Smith et al. 1983
Grasses		
Crested wheatgrass (Agropyron cristatum)	0.50 - 0.86	Shantz and Piemeisel (1927), Hull (1963), Fairburn (1982),
Western wheatgrass (*Pascopyrum smithii)*	0.45 – 1.03	Fairbourn (1982)
Purple threeawn (*Aristida purpurea*)	0.50 - 0.60	*Aristida divaricata* (McGinnis and Arnold 1939)
Sideoats grama (*Bouteloua curtipendula*)	0.55 – 1.09	McGinnis and Arnold (1939)
Blue grama (*Bouteloua gracilis*)	0.69 – 1.09	McGinnis and Arnold (1939), Weaver (1941)
Kentucky bluegrass (*Poa pratensis*)	1.70	Weaver (1941)
Little bluestem (*Schizachyrium scoparium*)	0.10 – 0.95	Polley et al. (1994), Polley et al (1996), Weaver (1941)
Sacaton (*Sporobolus airoides*)	0.44 – 0.97	*Sporobolus flexosus* (Dwyer and DeGarmo 1970)
Sand dropseed (*Sporobolus cryptandrus*)	0.44 – 0.97	*Sporobolus flexosus* (Dwyer and DeGarmo 1970)
Green needlegrass (*Stipa viridula*)	0.99 – 2.25	Fairbourn (1982), White and Brown (1972)
Japanese brome (*Bromus japonicus*)	0.15 – 0.39	Hull (1963), Link et al. (1995), Nasri et al. (1995)
Forbs		
Ragweed (*Ambrosia psilostachya*)	0.23	*Ambrosia dumosa* (Bamberg et al. 1975)
Spotted knapweed (*Centaurea maculosa*)	0.50	Blicker et al. (2003)
Canada thistle (*Cirsium arvensis*)	0.50	*Centuarea maculosa* (Blicker et al. 2003)
Bindweed (*Convolvulus arvensis*)	0.50	*Centuarea maculosa* (Blicker et al. 2003)
Scarlet beeblossum (*Gaura coccinea*)	1.39	*Melilotus officinalis* (Shantz and Piemeisel 1927)
Golden aster (*Heterotheca villosa*)	0.50- 0.90	*Artemisia frigida* (Briggs and Shantz 1913, Shantz and Piemeisel 1927)
Hoarhound (*Marrubium vulgare*)	0.50- 0.90	*Artemisia frigida* (Briggs and Shantz 1913, Shantz and Piemeisel 1927)
Alfalfa (*Medicago sativa*)	1.40	Power (1991)
Mignonette (*Reseda lutea*)	0.50- 0.90	*Artemisia frigida* (Briggs and Shantz 1913, Shantz and Piemeisel 1927)
Orange globemallow (*Sphaeralcea coccinea*)	0.50- 0.90	*Artemisia frigida* (Briggs and Shantz 1913, Shantz and Piemeisel 1927)
Wavyleaf thistle (*Cirsium undulatum*)	0.50- 0.90	*Artemisia frigida* (Briggs and Shantz 1913, Shantz and Piemeisel 1927)
Sweetclover (*Melilotus officinalis*)	1.39	Power (1991)
Lambsquarters (*Chenopodium album*)	0.09 – 0.31	Dwyer et al. (1972), Dwyer and Wolde-Yohannis (1972)
Sunflower (*Helianthus petiolaris*)	0.55 – 0.74	Shantz and Piemeisel (1927)
Bladderpod (*Lesquerella montana*)	0.55 – 0.74	*Helianthus petiolaris* (Shantz and Piemeisel 1927)
Russian thistle (*Salsola kali*)	0.09 – 0.31	Dwyer et al. (1972), Dwyer and Wolde-Yohannis (1972)
Tansymustard (*Sisymbrium altissimum*)	0.50	*Centuarea maculosa* (Blicker et al. 2003)